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MANEUVERING REQUIREMENTS AND MINIMUM MISS DISTANCES FOR HOMING MISSILES IN A RESTRICTED SET OF ANTI-TANK ENGAGEMENTS

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MANEUVERING REQUIREMENTS AND MINIMUM MISS DISTANCES FOR HOMING MISSILES IN A RESTRICTED SET OF ANTI-TANK ENGAGEMENTS

by

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ABSTRACT

The homing trajectory equations are solved for a limited set of anti-tank engagement parameters, resulting in quantitative data on required missile maneuverability to overcome various perturbations. The theoretical minimum miss distances (noiseless) are calculated for coasting terminal trajectories.

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I. INTRODUCTION

The trajectory equations that govern the kinematic behavior of missiles flying various proportional navigation trajectories are presented with the goal of establishing missile maneuvering requirements for a specific set of engagement parameters. These parameters are those that might be encountered in ground-to-ground tank engagements at the 2 to 3 kilometer range. Analog simulation results, based on the trajectory equations, show the maneuver capability required of a homing missile to overcome various perturbations.

In addition, a problem peculiar to seekers that track the target image contour is treated. This problem, that of guidance loss in the terminal tracking phase due to the increase in image size with decreasing range, results in a need for the missile to coast unguided for a fraction of this trajectory. The theoretical miss distances due to this phenomenon have been calculated and are also presented.

II. MISSILE PERFORMANCE REQUIREMENTS FOR PROPORTIONAL NAVIGATION

In proportional navigation, the missile turning rate ($\dot{\gamma}$) is made proportional to the line-of-sight (LOS) rate ($\dot{\sigma}$):

$$\dot{\gamma} = N\dot{\sigma}$$

N is the proportionality (navigation) constant. Figure I shows that the normal velocity component of the missile is given by: $y = V \sin\gamma \approx V\gamma$ for small angles; therefore, the normal acceleration is given by: $y = V\dot{\gamma} + \dot{V}\gamma \approx V\dot{\gamma}$ for a constant velocity missile.
Thus:

$$\dot{\gamma} = \frac{\ddot{y}}{V} \quad \text{and} \quad \ddot{y} = NV\dot{\sigma}$$

One practical means of attaining proportional navigation is to carry onboard the missile a tracking device capable of measuring the LOS rate and using this information to command a lateral acceleration proportional to this rate. A means of measuring $\dot{\sigma}$ can be explained with the aid of Figure I. A gimballed seeker attempts to track the target, i. e. reduce the error angle ϵ to zero. This angle exists because the tracker cannot have an infinitely fast response and will thus lag behind the LOS by an amount determined by the tracking loop time constant (τ). Thus the instantaneous value of the angle μ is given by:

$$\mu = \frac{\sigma}{1+\tau s}$$

From Figure I it is obvious that $\epsilon = \sigma - \mu$, and thus:

$$\epsilon = \sigma - \frac{\sigma}{1+\tau s} = \frac{\sigma + \sigma\tau s - \sigma}{1+\tau s} = \frac{\tau s}{1+\tau s}\sigma$$

Therefore, the instantaneous tracker error angle, a rather easily measured quantity, can be used to effect proportional navigation if we multiply it by some gain factor λ and use the resulting value to command a missile acceleration:

$$a_m = \lambda\epsilon = \frac{\lambda\tau s}{1+\tau s}\sigma \qquad (1)$$

where a_m = missile lateral acceleration in g's.

The above equation will be used in the derivation of the homing trajectory differential equations. These equations are greatly simplified if we use the constant-bearing (collision) course (Reference 1 and 2) as a reference and consider the proportional course as perturbations about this reference. Such a reference frame is shown in Figure II, and the associated symbols are identified in Table I. From the figure, we obtain:

$$\ddot{Z}_m = -a_m g \qquad (2)$$

i. e. the commanded acceleration of the missile normal to the reference course is directed so that it tends to eliminate Z_m, thus the negative sign. Combining equations 1 and 2:

$$\ddot{Z}_m = -\frac{g\lambda\tau s}{1+\tau s}\sigma$$

or, converting the whole equation to time domain:

$$\tau\dddot{Z}_m + \ddot{Z}_m = -g\lambda\tau\dot{\sigma}$$

Integrating above:

$$\tau\ddot{Z}_m + \dot{Z}_m = -g\lambda\tau\sigma + C \qquad (3)$$

C is the constant of integration (initial conditions) and is given by:

$$C = \tau\ddot{Z}_m\big|_{o+} + \dot{Z}_m\big|_{o+} + g\lambda\tau(\sigma\big|_{o+})$$

where o+ denotes value of variable at t = o

Equation 3 can then be written:

$$\tau\ddot{Z}_m + \dot{Z}_m = -g\lambda\tau\sigma + \tau\ddot{Z}_m\Big|_{0+} + \dot{Z}_m\Big|_{0+} + g\lambda\tau\left(\sigma\Big|_{0+}\right) \quad (4)$$

Equation 4 is then the trajectory differential equation and can be solved if σ can be determined. Since σ is generally small, the simplifying approximation $\sigma \approx \tan\sigma$ can be used. From Figure II it is also clear that the tangent of σ is given by:

$$\tan\sigma \approx \sigma = \frac{(\overline{1}+\overline{2})-(\overline{3}+\overline{4})}{R_t} \quad \text{or}$$

$$\sigma = \frac{(X_m \sin\delta + Z_m \cos\delta) - (X_t \sin\psi + Z_t \cos\psi)}{R_t}$$

Since $R_t = \dot{R}\,(t_o - t)$ where:

$\dot{R}$ = range rate = V_c = closing velocity
t_o = nominal homing time = R_o/V_c
t = elapsed flight time

Introducing above value of σ into equation 4 and substituting $V_c\,(t_o - t)$ for R, we obtain the complete trajectory differential equation:

$$\tau\ddot{Z}_m + \dot{Z}_m = \frac{-g\lambda\tau}{V_c(t_o-t)}(X_m\sin\delta + Z_m\cos\delta - X_t\sin\psi - Z_t\cos\psi) + \tau\ddot{Z}_m\Big|_{0+} + \dot{Z}_m\Big|_{0+} + g\lambda\tau\left(\sigma\Big|_{0+}\right)$$

Transposing $Z_m \cos\delta$ to the left side, we obtain:

$$\tau\ddot{Z}_m + \dot{Z}_m + \left(\frac{g\lambda\tau\cos\delta}{V_c\,(t_o-t)}\right)Z_m = \frac{-g\lambda\tau}{V_c\,(t_o-t)}(X_m\sin\delta - X_t\sin\psi - Z_t\cos\psi) + \tau\ddot{Z}_m\Big|_{0+} + \dot{Z}_m\Big|_{0+} + g\lambda\tau\left(\sigma\Big|_{0+}\right) \quad (5)$$

The term $\dfrac{g\lambda\tau\cos\delta}{V_c}$ is almost constant for small deviations from a collision course and is generally defined as the effective navigation constant N'. A more common expression for N' is given by:

$$N' = \frac{V_m N\cos\delta}{V_c}$$

The above two expressions can be shown to be equivalent if the following equality can be demonstrated:

$$g\lambda\tau = V_m N$$

This can be done as follows:

It has been shown that the seeker measures $\tau\sigma$ but with a lag $(1+\tau s)$ term. Thus, since the basic error is $\tau\dot{\sigma}$, then from equation 1, the basic commanded acceleration is:

$$a_m = \lambda\tau\dot{\sigma} \tag{6}$$

From the basic navigation law, we have shown:

$$\ddot{y} = NV_m\dot{\sigma} \quad \text{or} \quad a_m = \frac{NV_m}{g}\dot{\sigma} \tag{7}$$

Equating the right sides of equations 6 and 7, we obtain:

$$\lambda\tau = NV_m/g \quad \text{or} \quad \lambda\tau g = NV_m$$

Dividing and multiplying the right side of equation 5 by cos δ and substituting N', we obtain:

$$\tau\ddot{Z}_m + \dot{Z}_m + \frac{N'Z_m}{t_o - t} = \frac{-N'}{t_o - t}\left(X_m \tan\delta - X_t\frac{\sin\psi}{\cos\delta} - Z_t\frac{\cos\psi}{\cos\delta}\right) + \tau\ddot{Z}\Big|_{0+} + g\lambda\tau\left(\sigma\Big|_{0+}\right) + \dot{Z}\Big|_{0+} \tag{8}$$

The preceding trajectory equation is a linear differential equation (time varying coefficients). Since the principle of superposition applies, the equation can be solved for certain specific conditions of interest one at a time and the results linearly combined. Of particular interest is the solution of Z_m for the following conditions:

1. An initial missile heading error, i. e. the missile is not pointed at the target at launch.
2. An acceleration bias. This can be caused by thrust malalignment, improper gravity correction, etc.
3. A maneuvering target.

4. An initial tracking error, such as would be caused by improper seeker pointing at launch.

Given typical values for the above four conditions, the solution of equation 8 for $\ddot{Z}_m$ yields the important specification of required missile maneuverability. The analog computer studies to be discussed are concerned with obtaining this specification. Since no one specific missile is under consideration, a range of representative parameters have been selected so that the data may be applicable to a wide range of vehicles. The general environment considered is that of a ground-to-ground engagement at ranges of 6000 and 10,000 feet. Since in this case gravity acceleration acts normal to the flight path, the results obtained are valid for either pitch or yaw. This is due to the fact that for the ground-to-ground case an external "g" bias would be required to overcome the gravitational acceleration, and is thus not part of the closed loop dynamics. If the navigation law were to be used to overcome the effect of gravity, an excessive portion of the missile's maneuvering capability would have to be employed; additionally, the ground clearance problem would become overwhelming unless the missile were to be launched into a high initial trajectory. This could be done by initiating guidance after launch, and the problem would be reduced to one of overcoming an acceleration bias, a case treated herein.

A. Case 1 - An initial heading error

From Figure II it is evident that $\dot{Z}_m\big|_{0+} = V_m \sin \gamma_0 \approx V_m \gamma_0$
With all other initial conditions = 0, equation 8 becomes:

$$\tau \ddot{Z} + \dot{Z}_m + \frac{N' Z_m}{t_0 - t} = -V_m \gamma_0$$

or, since $t_0 - t = R/V_c$

$$\tau \ddot{Z}_m + \dot{Z}_m + \frac{N' Z_m}{t_0 - t} = -V_m \gamma_0 \tag{9}$$

A computer program for equation 9 is shown in Figure III. The scale factors shown are only one set of several used. The scale changes were necessitated by the dynamic range of the equations and by noise problems. Graphs 1 through 9 show plots of $\ddot{Z}_m$ versus range for a set of representative conditions. (ϕ in the graphs refer s to γ_0). Several interesting observations can be made from these plots. The individual plots on Graphs 1 and 2 show the effect of changing τ only. The magnitude of the required $\ddot{Z}_m$ does not change with τ ; however, the range at which the peak value of $\ddot{Z}_m$ occurs does change considerably. This is also evident from Graphs 4 and 5 where the initial conditions are the same as for 1 and 2, except for initial range. The longer

range results in a decrease in required peak acceleration.

Graphs 3 and 6 through 9 show the effect on the required $\ddot{Z}_m$ of increased N' and velocity. It is evident that an increase in either parameter results in an increase in missile maneuver requirements. The implication is that missile flight time and navigation ratio are the critical parameters of interest. This is evident from equation 9. If we replace V_c/R by $1/t_0-t$, Jerger (Reference 1) has shown that for a given navigation constant and initial conditions, the acceleration requirements are dependent solely on the ratio t_0/τ . This term is denoted "control system stiffness." For example, in the first set of plots in graph 1, $t_0/\tau = 12$. The $\ddot{Z}_m$ values would be equally valid for R = 12,000 feet and V = 2000 ft/sec since t_0/τ would remain unchanged. Another useful generalization can be stated as follows. For $t_0/\tau > \angle 0$, the system does not deviate considerably from a perfect system ($t_0/\tau = \infty$).

B. Case 2 - An acceleration bias

If an acceleration bias exists in the missile, an additional fixed acceleration will be commanded in addition to that called for by the navigation law. Equation 1 then becomes:

$$a_m = a_b + \frac{\lambda \tau s}{1+\tau s}\sigma$$

The term a_b will appear after one integration as $a_b t$ in equation 3 and as $-a_b t$ on the right side of equation 8.

If we assume no perturbations and no initial heading error, equation 8 reduces to:

$$\tau\ddot{Z}_m+\dot{Z}_m+\frac{N'Z_m}{t_0-t} = -a_b t + \tau\ddot{Z}\Big|_{0+}$$

Since $\ddot{Z}\Big|_{0+} = -a_b$ and $(t_0-t) = R/V_c$ the above equation reduces to:

$$\tau\ddot{Z}_m + \dot{Z}_m + \frac{N'V_c}{R}Z_m = -a_m(t+\tau) \qquad (10)$$

The right side (forcing function) of the above equation is the only term that differs from equation 9. Thus, with the one exception, the same computer program may be used. Mechanization of the term $-a_m(t+\tau)$ is shown in Figure IV. Plots of the values of $\ddot{Z}_m$ required to overcome

bias errors of 1/4, 1/2, and 1 "g" are shown in Graphs 10-16.

C. Case 3 - A maneuvering target

The case for a maneuvering target can be considered as follows:

Let $\ddot{Z}_m\Big|_{0+} = \dot{Z}_m\Big|_{0+} = \sigma\Big|_{0+} = X_m = X_t = 0$

and $Z_t = \frac{1}{2} a_t t^2$ (constant acceleration target).

Then equation 8 can be written:

$$\tau\ddot{Z}_m + \dot{Z}_m + \frac{N'V_c}{R} Z_m = \left[- \frac{N'V_c \cos\psi \; a_t t^2}{2R\cos\delta}\right]$$

If we consider the most severe case, i.e. the initial missile-target collision course is along a straight line (head on engagement) and the direction of target maneuver is normal to this, the above equation can be written:

$$\tau\ddot{Z}_m + \dot{Z}_m + \frac{N'V_c Z_m}{R} = - \frac{N'V_c a_t t^2}{2R}$$

This equation is again identical to the other cases considered except for the forcing function. Thus the computer program on Figure III can again be used with a suitable modification for the term of the right side. This is shown in Figure V. Plots of the required missile acceleration for two magnitudes of target maneuver (4 ft/sec^2 and 8 ft/sec^2) and a representative set of engagement parameters are shown in Graphs 17 through 22. From these graphs, it is evident that the missile maneuver requirements increase considerably as the target is approached.

D. Case 4 - An initial tracking error

If the missile borne seeker exhibits a tracking error ϵ_0 at t = 0, due to imperfect aiming, it will deviate from its correct course and restoring commands are generated. The effect of ϵ_0 can be evaluated by solving equation 8 for the case where it is the only perturbation. It has been shown (Reference 1) that the trajectory equation forcing function for this case is given by: $-V_c N' \epsilon_0/\cos\delta$

Thus the trajectory equation becomes:

$$\tau\ddot{Z}_m + \dot{Z}_m + N'V_c Z_m/R = V_c N' \epsilon_0/\cos\delta$$

The mechanization of the forcing function is simply a properly scaled step input and is shown in Figure VI. The plots of $\ddot{Z}_m$ for various parameters of interest are shown in Graphs 23 through 29.

The plots indicate that very large initial accelerations are required; however, we should keep in mind that the values of ϵ_0 employed are also quite large. Initial tracking error much smaller than 1° - 3° should be realizable without excessive difficulty.

III. THEORETICAL MINIMUM MISS DISTANCE VERSUS COAST RANGE

The employment of an image contour tracker as the error sensing element in a homing missile presents a multitude of peculiar problems. One of these is related to the angle subtended by the target in the field-of-view and is of interest due to the following reasons:

1. At maximum range, the field-of-view of the optics must be small enough to yield a target image large enough to exceed the resolution limitations of the TV seeker.

2. As the missile nears the target, the image will subtend a proportionally larger portion of the field-of-view, until eventually the image to field area ratio becomes unity and tracking information is lost. The missile must then coast unguided to the target. For hardware presently under development, the field-of-view limitation is approximately 2° for an initial range of 2 kilometers. Considering a 7 1/2 x 7 1/2 foot target, the missile must coast for approximately the last 250 feet. For a 3 kilometer initial range, the coast distance becomes approximately 500 feet.

Miss distance calculations are extremely complex and involve many probabilistic and design factors. Our concern here is to determine the miss distance due only to target maneuver during the missile coast period when trajectory corrections cannot be effected. Two alternatives are discussed.

A. Neutral Command Terminal Trajectory

In this scheme, when loss of track occurs, the control surfaces return to neutral and result in a straight line missile trajectory. The miss distance can then be approximated by the target travel normal to the collision course during the missile coast period. These values are tabulated in Table I for two values of target acceleration and initial range, and for several values of missile velocity. The miss distance (m) is given by:

$$m = 1/2 \; a_t t_s^2$$

where a_t = target acceleration normal to LOS
t_s = coast flight time

B. Retention of Last Command Prior to Loss of Track

If the control system is locked in a certain position at some

time t, the miss distance for maneuvering target can be found by studying an equivalent case, that of acceleration saturation. This occurs when the engagement dynamics due to target maneuver are such that the navigation law calls for a command that exceeds the missile's capability. The two cases are analogour, and the miss distance can be calculated by assuming that acceleration saturation occurs when the seeker loses track. The derivation of m is given in Reference 1 for the case where $\tau = 0$:

$$m = \frac{a_t}{2} \frac{(t_o - t_s)}{t_o} N' \times t_o^2$$

where $t_o = R/V_c$

$$t_s = t_o - R/V_c$$

Miss distances were calculated for the same parameters as Case A and the results are shown in Table II. It is evident that the values of m are negligible. It is true that the $\tau = 0$ assumption is not quite valid; however, an useful approximation is obtained. Additionally, one general important conclusion can be made, i.e. it is at least theoretically possible to hit a moving tank-sized target with a missile that employs the contrast controut tracker (CCT) under consideration

IV. CONCLUSIONS

It has been shown that for a perfet system, the miss distances resulting from terminal coasting into maneuvering targets capable of tank-type accelerations are quite insignificant. This of course, is based on the assumption that the missile retains its last correct command prior to loss of track. If the control system is returned to its neutral positions, the miss distances increase accordingly.

Quantitative data on the missile performance requirements to overcome several important perturbations has been obtained. A sufficient variety of parameters has been employed in an attempt to cover the probable values for a CCT-type system. It has been shown that the data obtained can be extended to other than the cases shown, provided that the missile velocity and engagement range are such that t_o remains unchanged. In addition, the equations and analog programs for each case have been presented, and thus further data could be obtained rapidly if necessary.

Given a specific set of missile and attack parameters, the proper graphs may be consulted to determine the maximum acceleration required to overcome given disturbances. For example, if V_m = 1000 ft/sec, R_o = 6000 feet, $t_o/\tau = 12$ and τ = 0.5. What missile acceleration is required to overcome an initial leading error of 5^o? Graph 3 indicates that 50 ft/sec^2 at a range of 4800 feet is required.

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3. Locke, A. S., Guidance, D. Van Nostrand Co., 1955.

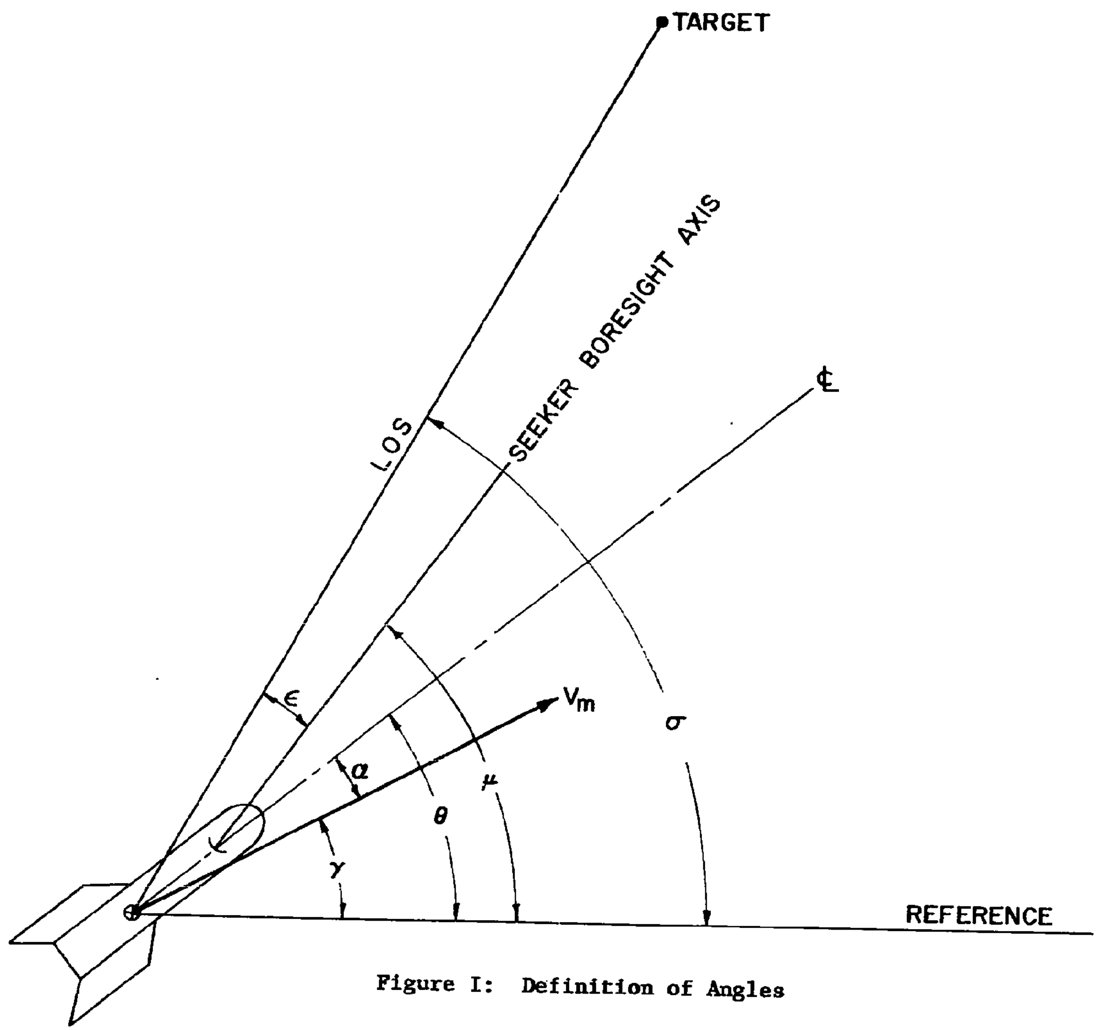


Figure I: Definition of Angles

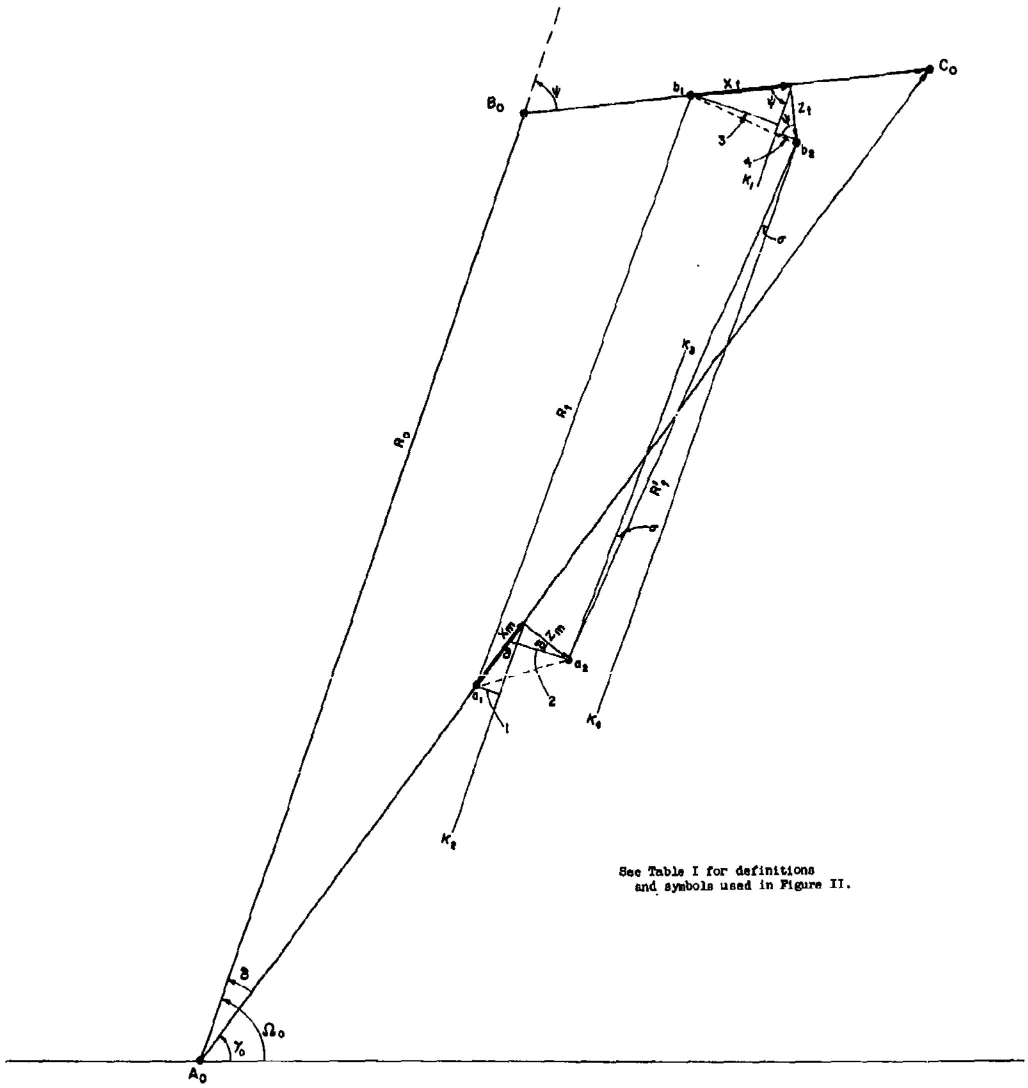


Figure II:. Missile-Target Geometry

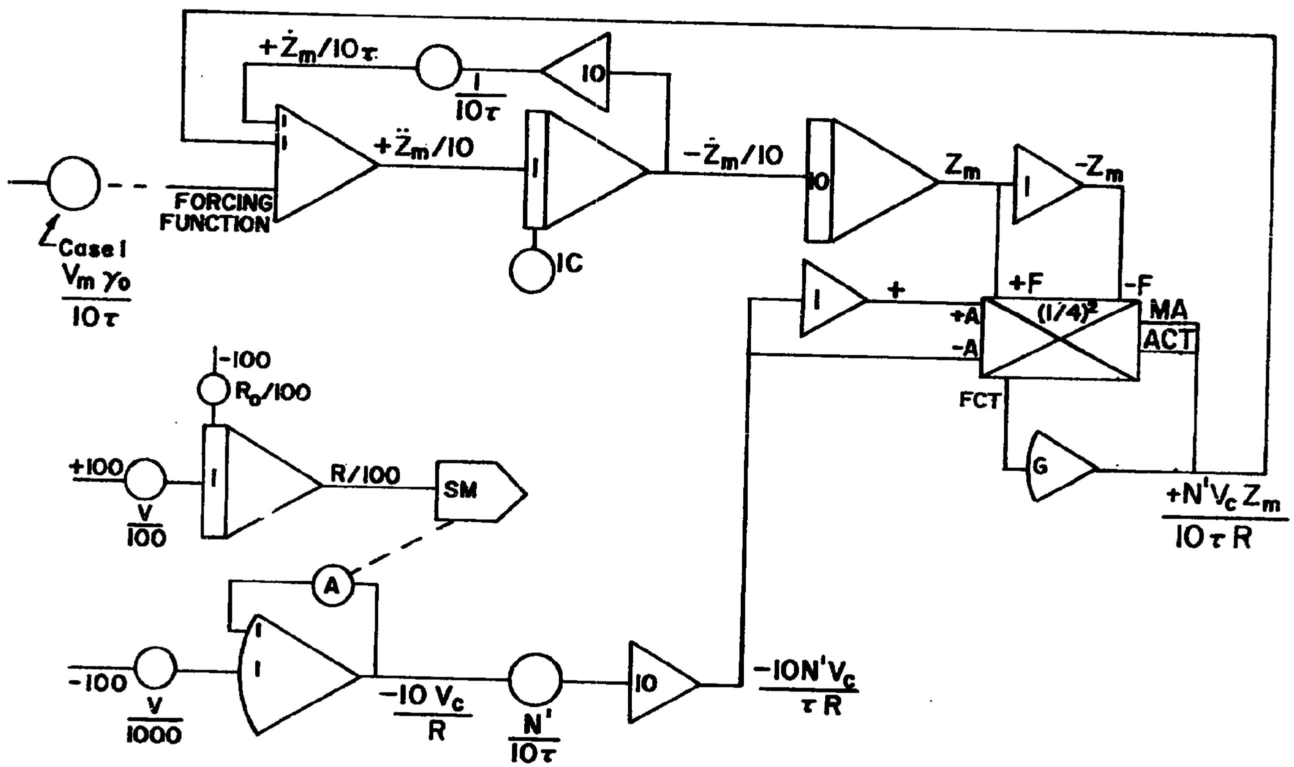


FIGURE III - Computer Diagram for Trajectory Equations

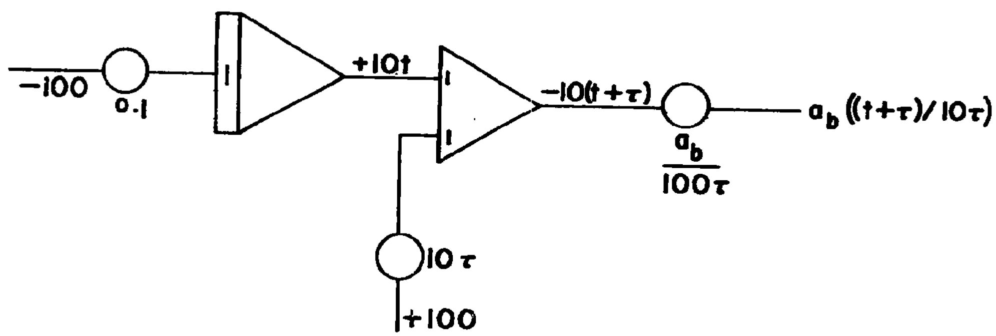


FIGURE IV: Computer Diagram - Forcing Function for Case 2

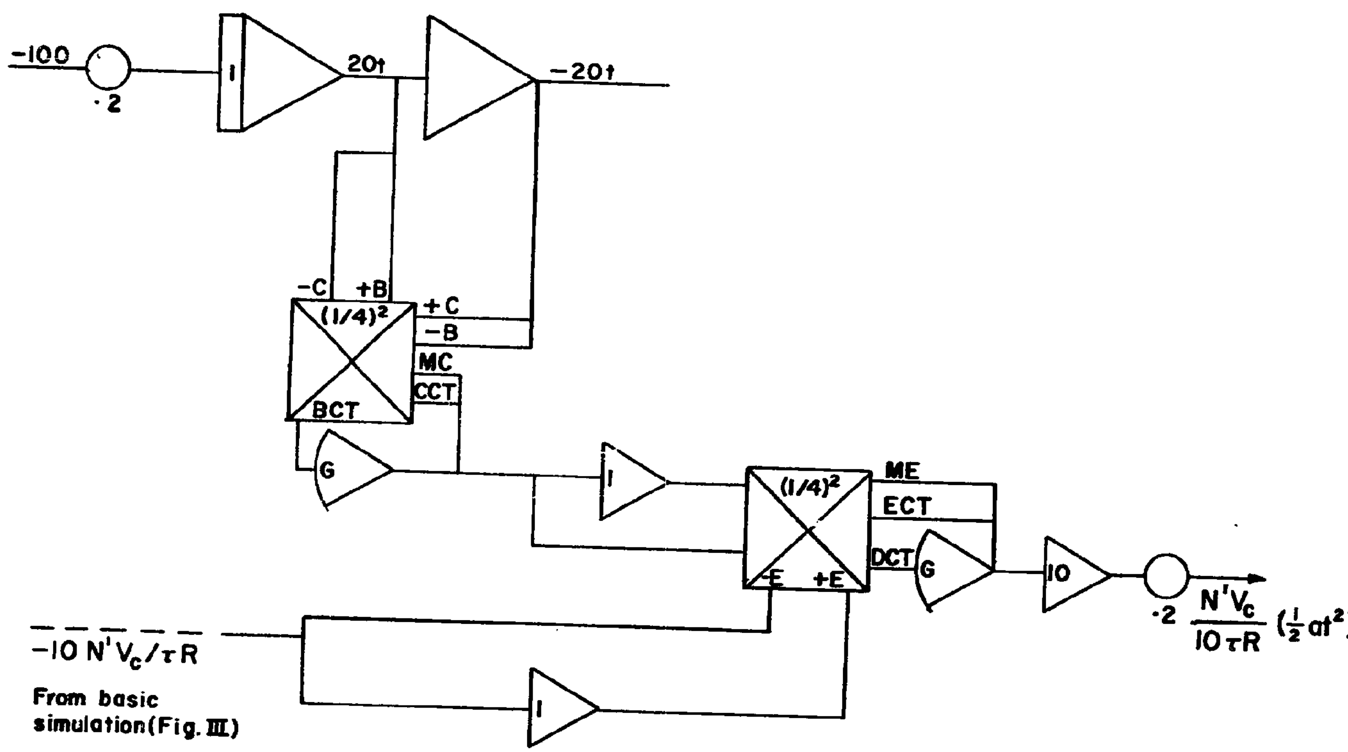


FIGURE V: Computer Diagram - Forcing Function for Case 3

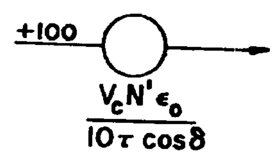


FIGURE VI: Computer Diagram - Forcing Function for Case 4

TABLE I

Definitions and Symbols for Figure II

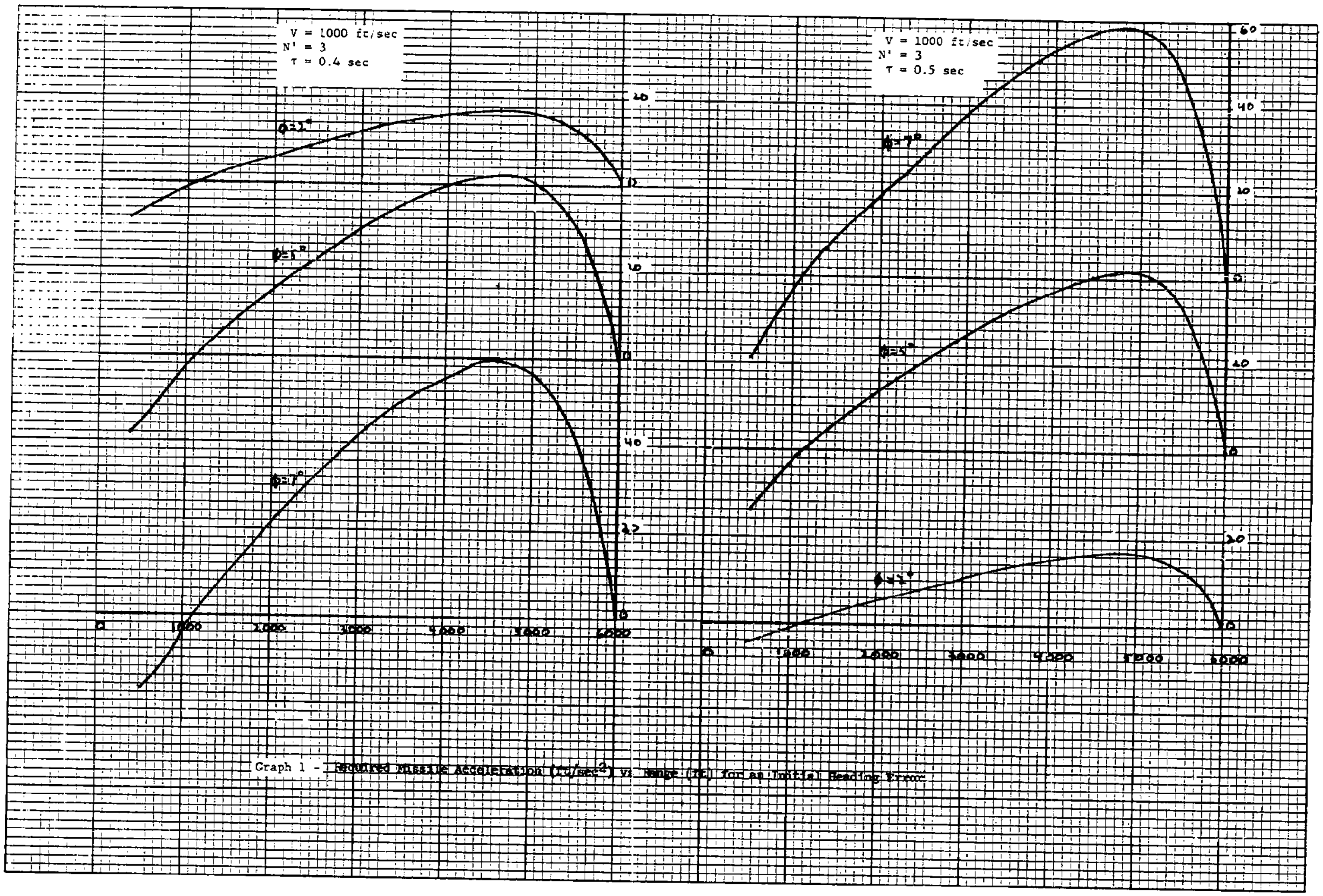
R_o	Initial range
R_t	Range at time t for reference collision course
R_t	Actual range at time t
k_1, k_2, k_3, k_4	Auxiliary lines, parallel to R_o
A_o B_o C_o	Collision triangle for constant bearing course
a_1, b_1	Reference missile and target positions at time t
a_2, b_2	Actual (perturbed) missile & target positions at time t
1, 2, 3, 4	Auxiliary lines perpendicular to R_o
x_m, x_t	Longitudinal missile and target perturbations
z_m, z_t	Traverse missile and target perturbations
δ	Missile lead angle
ψ	Target aspect angle
σ	Line of sight perturbation angle
Ω_o	Initial LOS angle from reference

V_m	R = 6000 ft		R = 10000 ft	
	a_t =4ft/s^2	a_t= 8ft/s^2	a_t = 4	a_t = 8
500 ft/s	0.5 ft	1.0 ft	2.0 ft	4 ft
1000	0.125	0.25	0.5	1 ft
2000	0.03125	0.0625	0.125	0.25

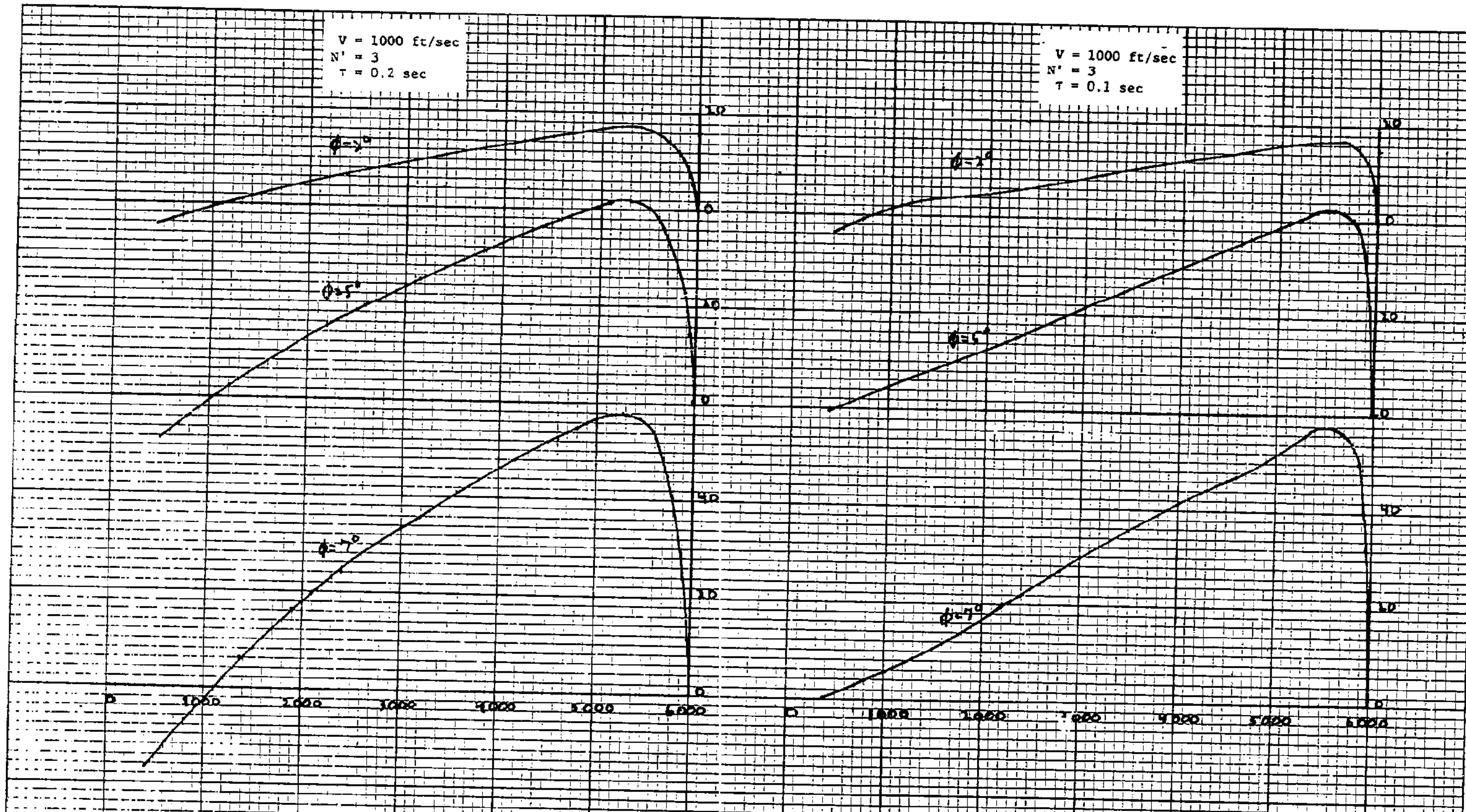
TABLE II: MISS DISTANCES FOR CASE "A"

	R = 6000 ft				R = 10000 ft			
V_m	N' = 3		N' = 4		N' = 3		N' = 4	
	a_t = 8ft/s^2	a_t = 4ft/s^2	a_t = 8	a_t = 4	a_t = 8	a_t = 4	a_t = 8	a_t = 4
500 ft/s	0.042 ft	0.021 ft	0.0018 ft	0.00087 ft	0.2 ft	0.1 ft	0.01 ft	0.005 ft
1000	0.0104	0.0052	0.00043	0.00022	0.06	0.03	0.0025	0.00125
2000	0.0026	0.0013	0.00011	0.000054	0.013	0.0065	0.000125	0.000625

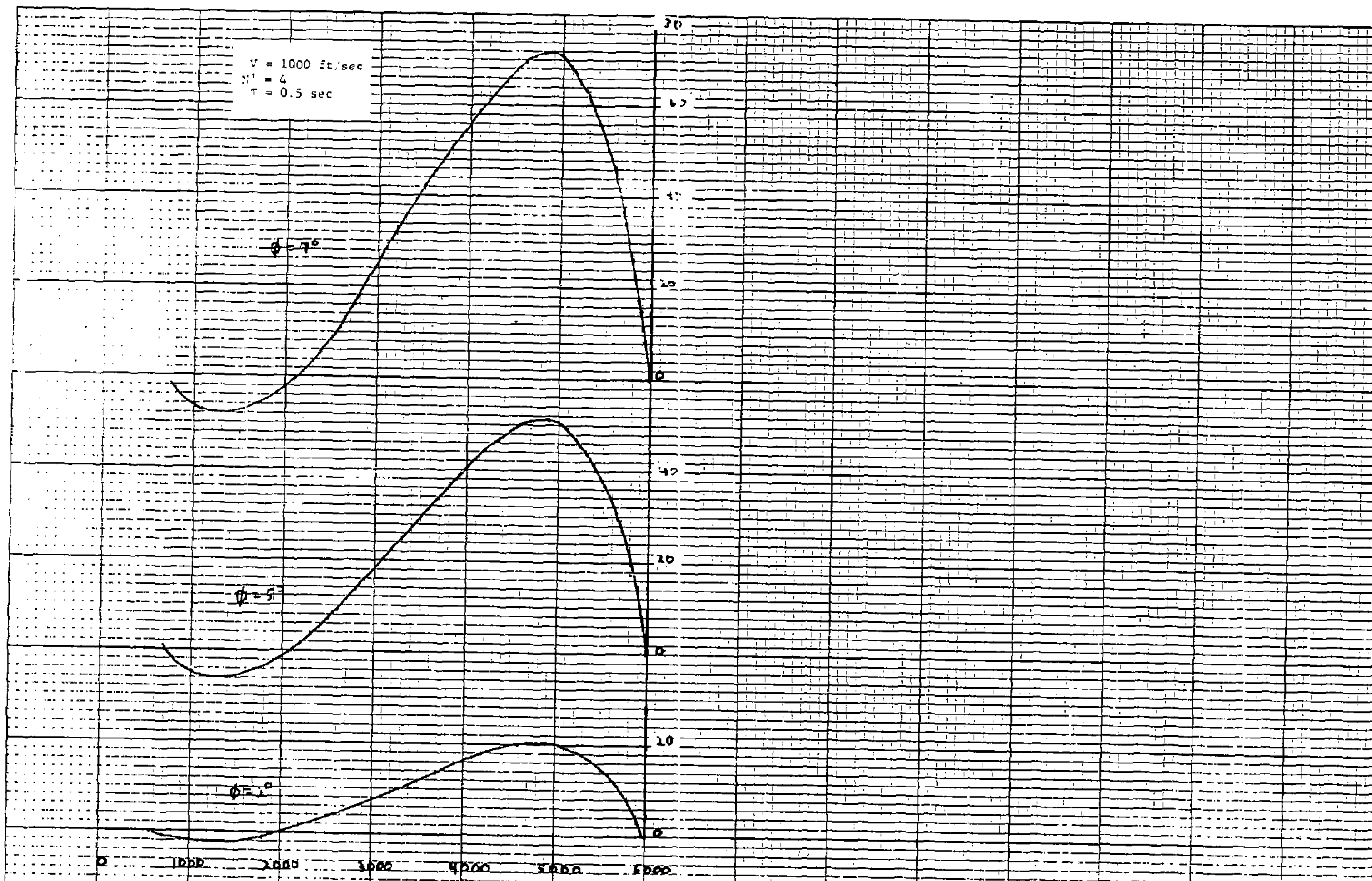
TABLE III: MISS DISTANCES FOR CASE "B"



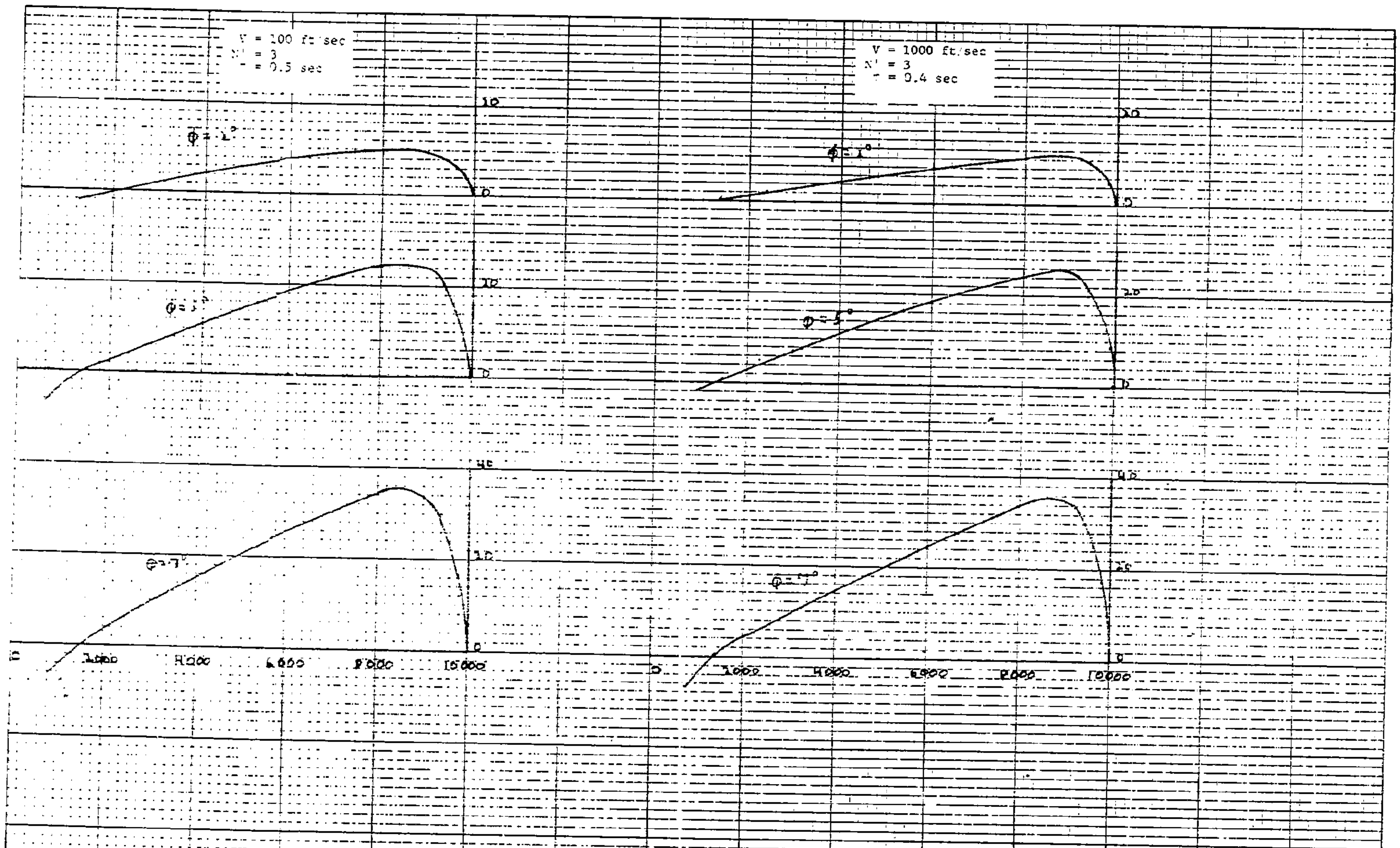
Graph 1 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



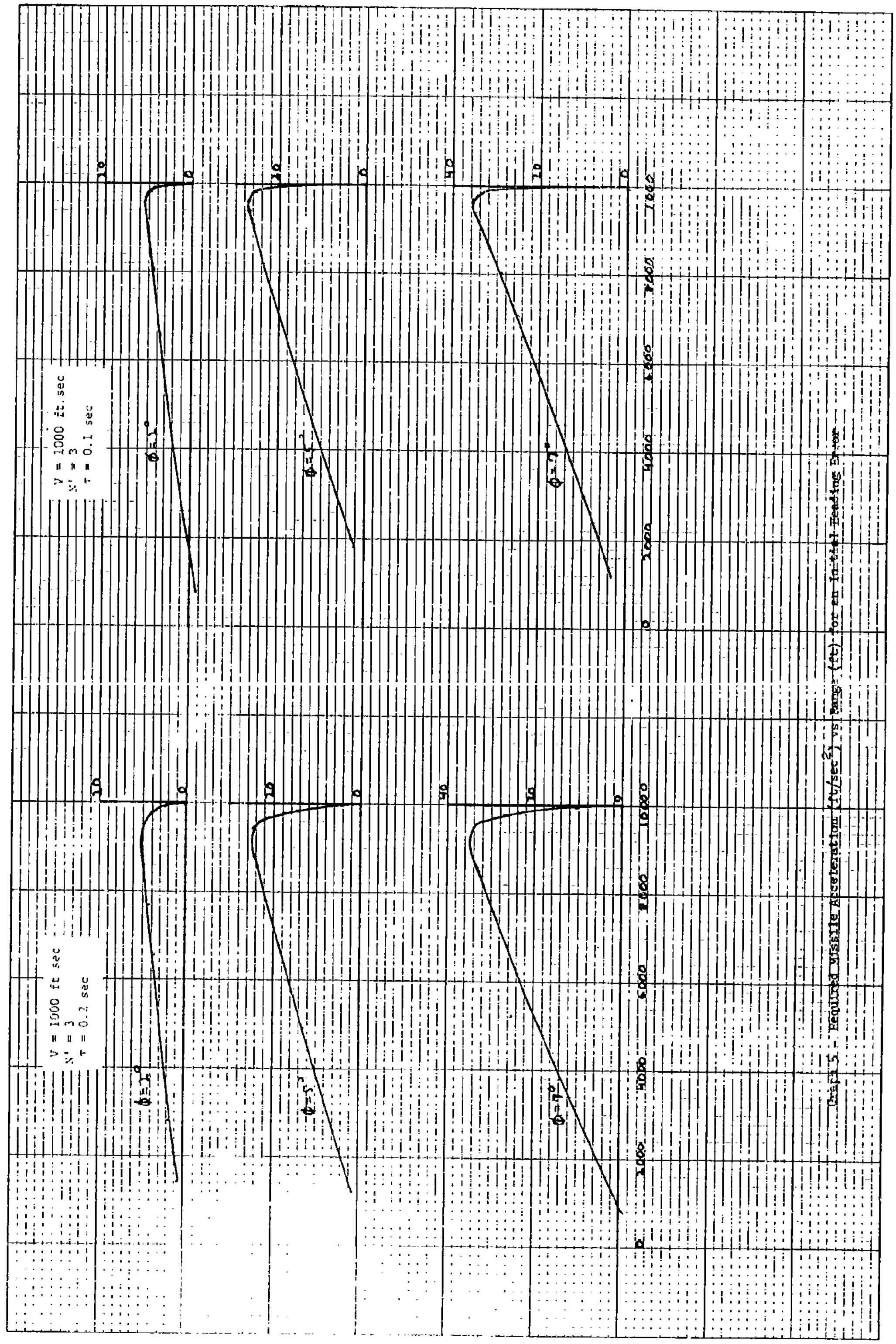
Graph 2 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



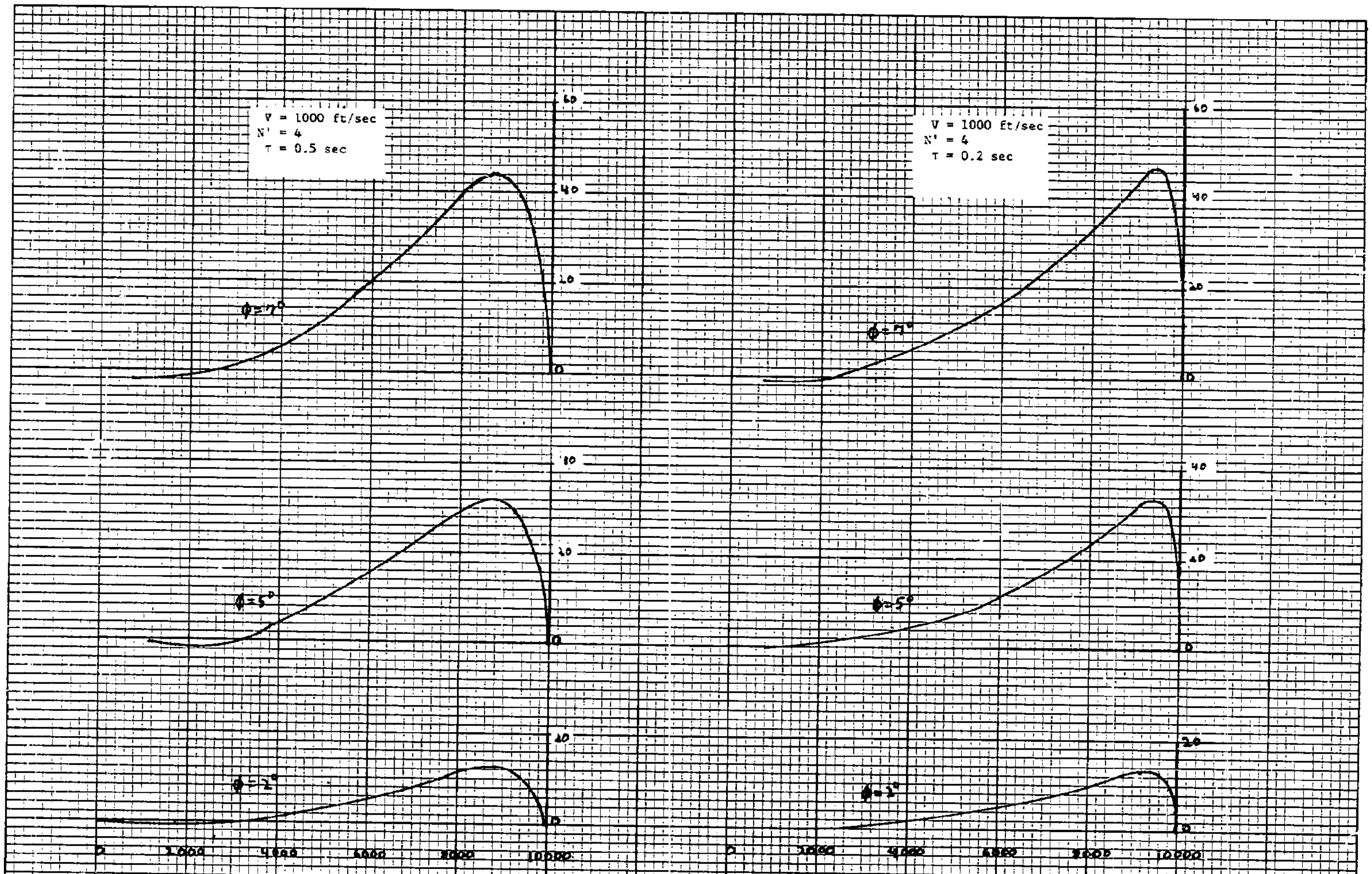
Graph 3 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



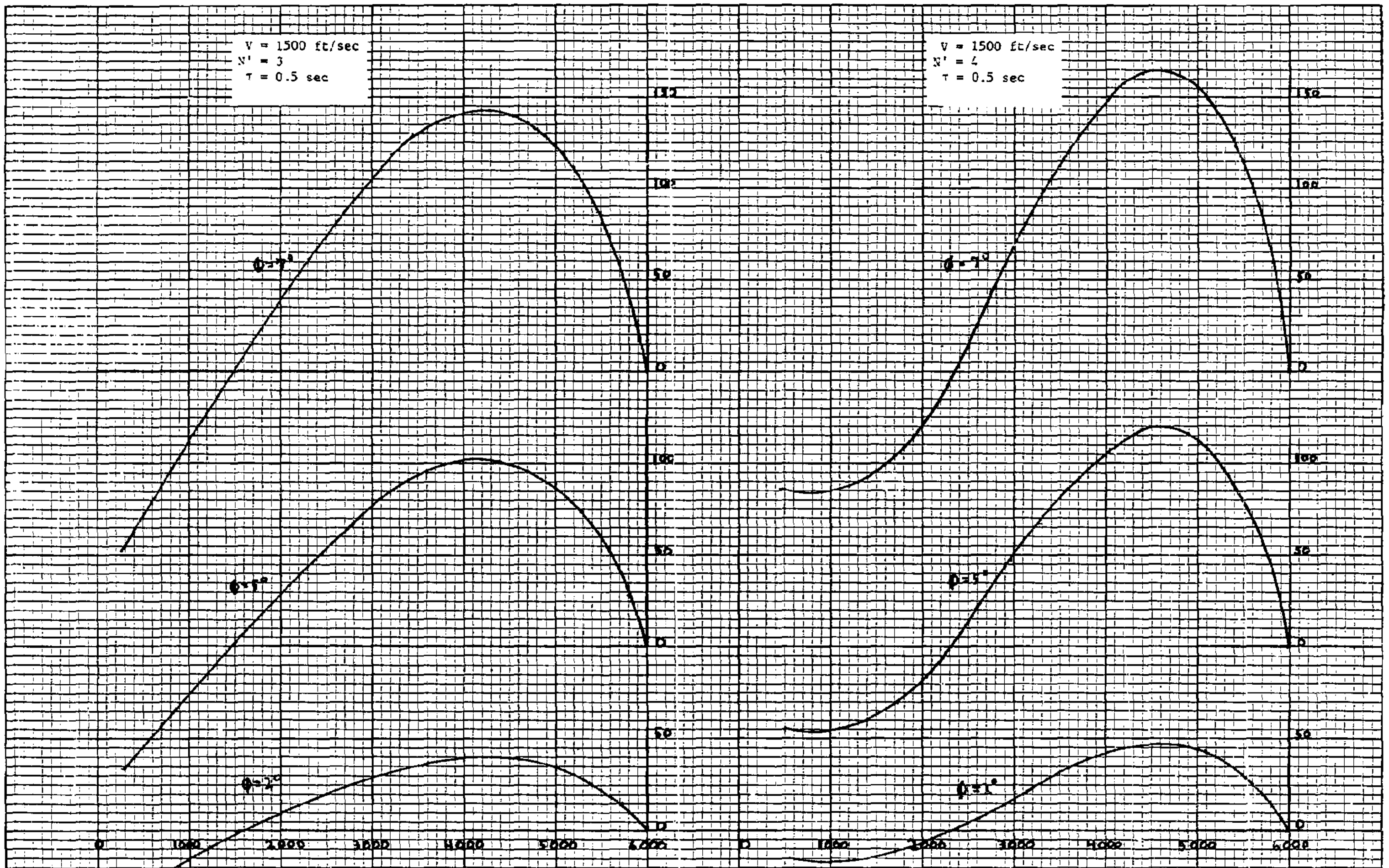
Graph 1 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



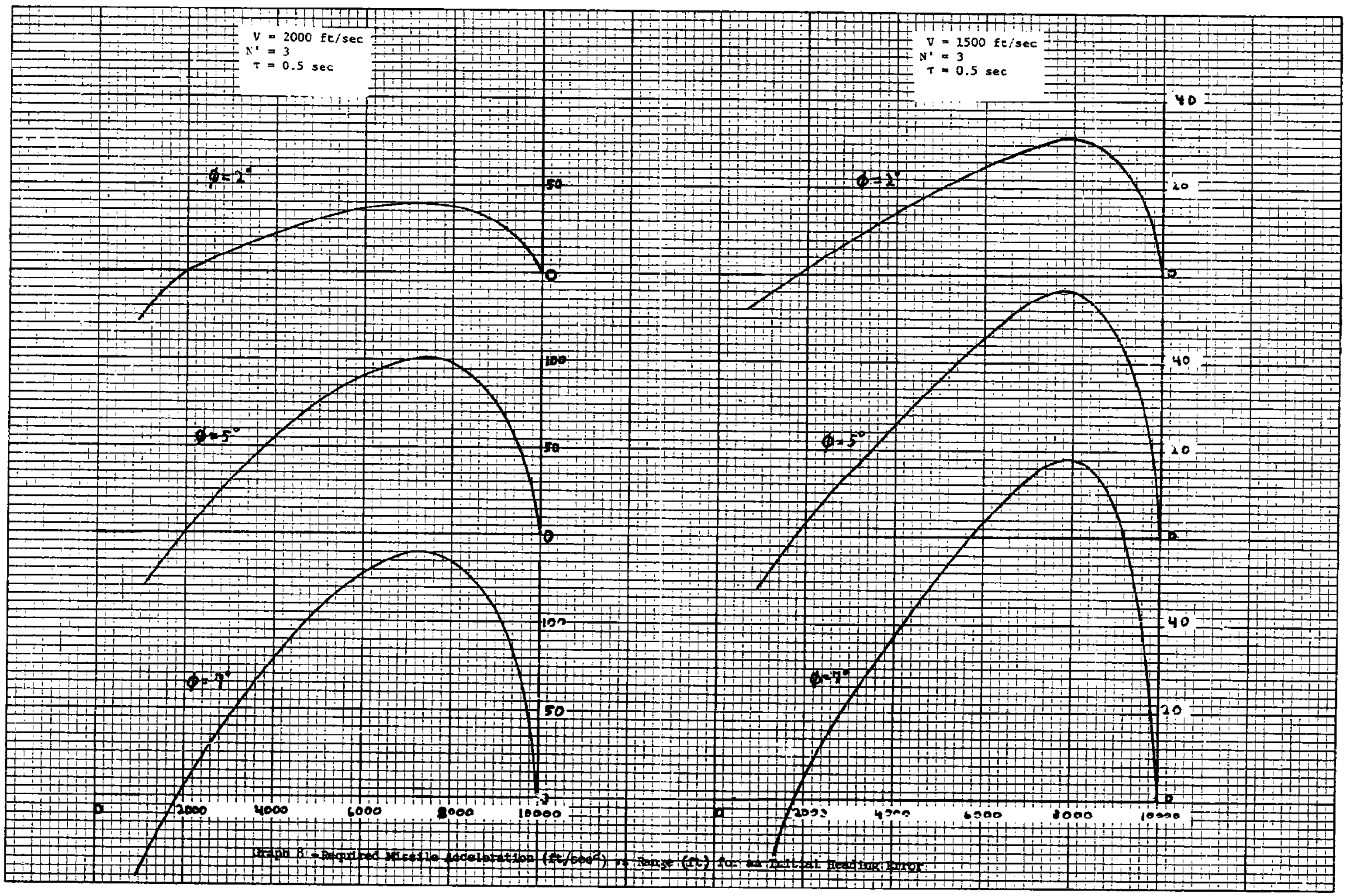
Graph 5 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



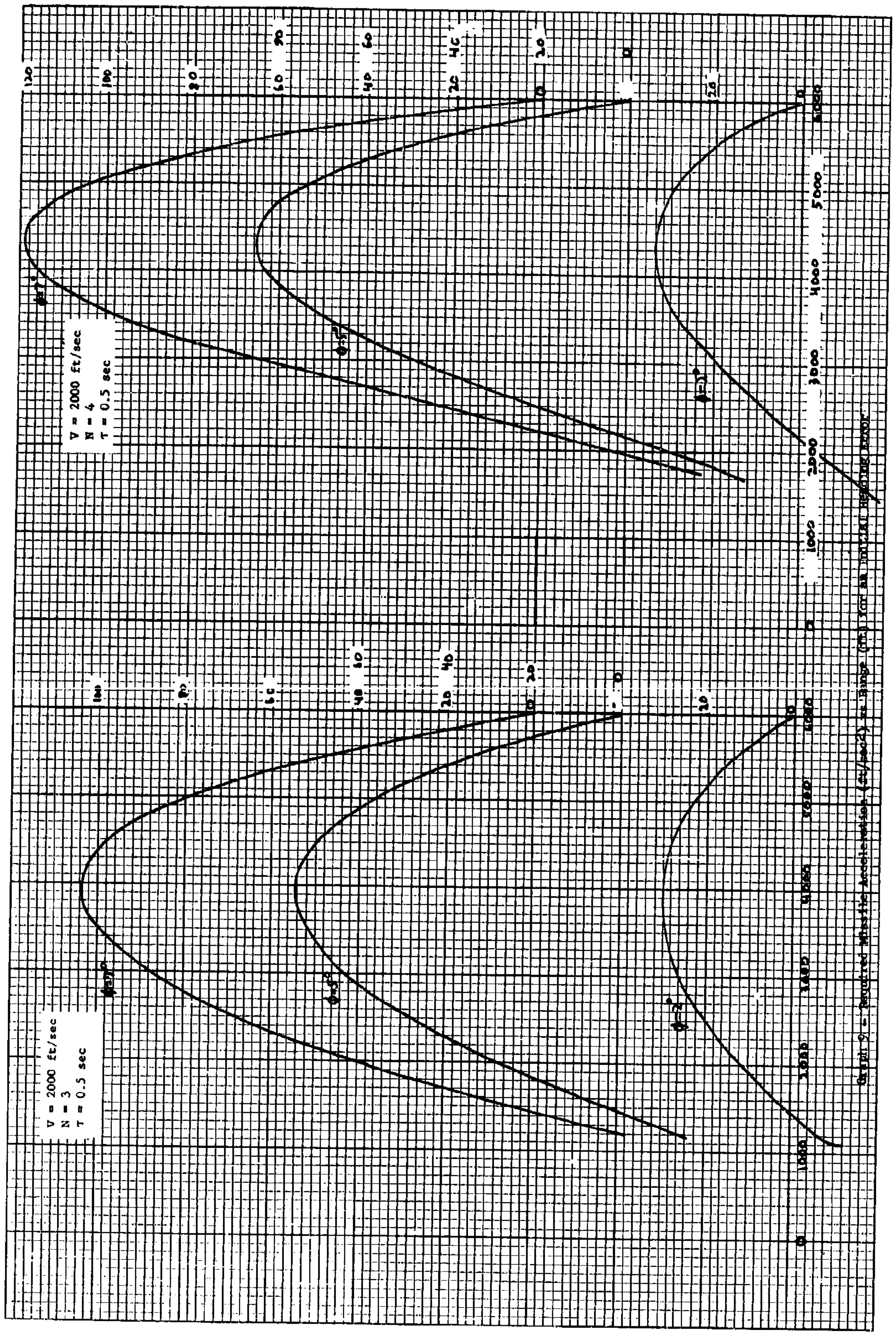
Graph 6 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



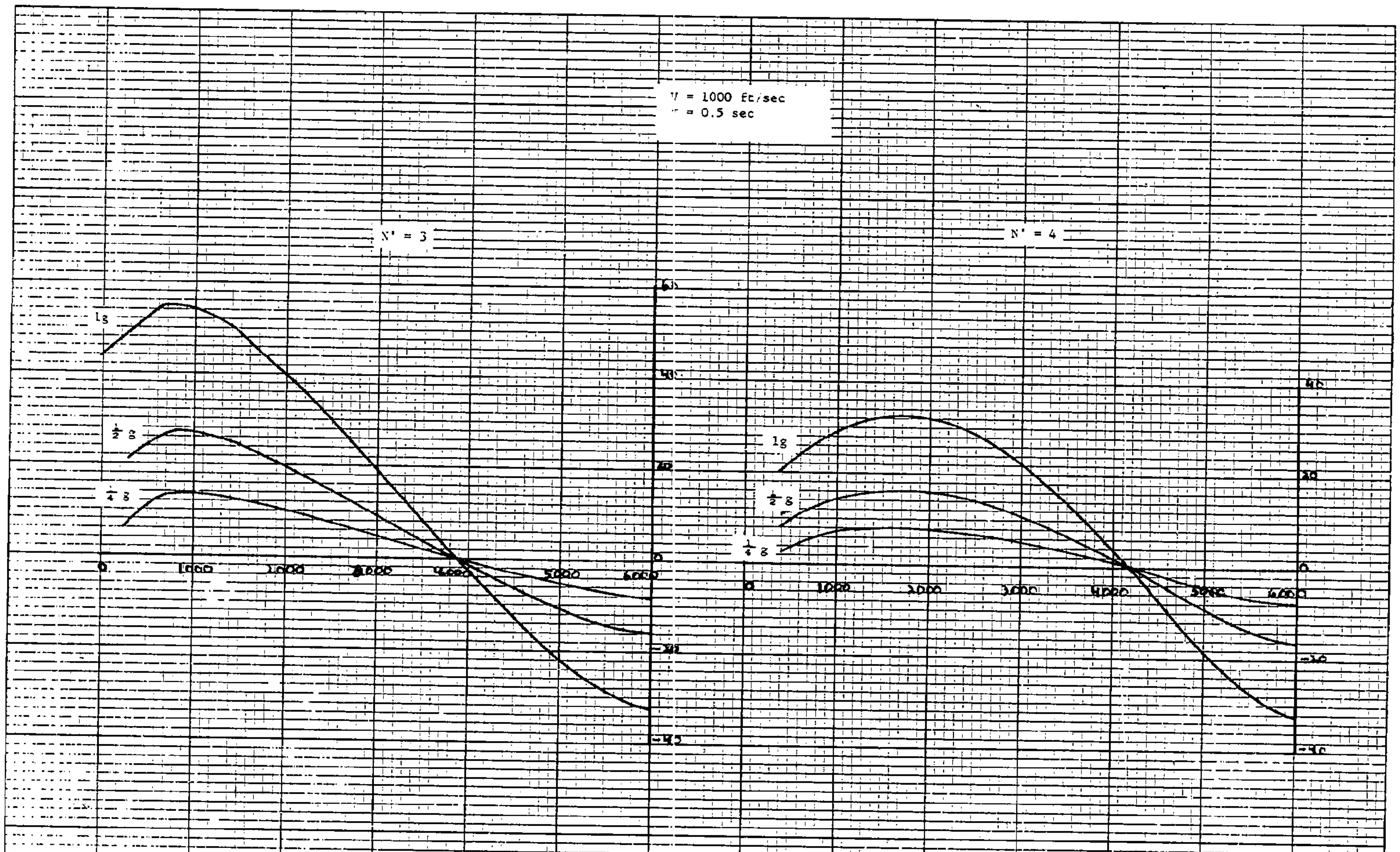
Graph 7 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



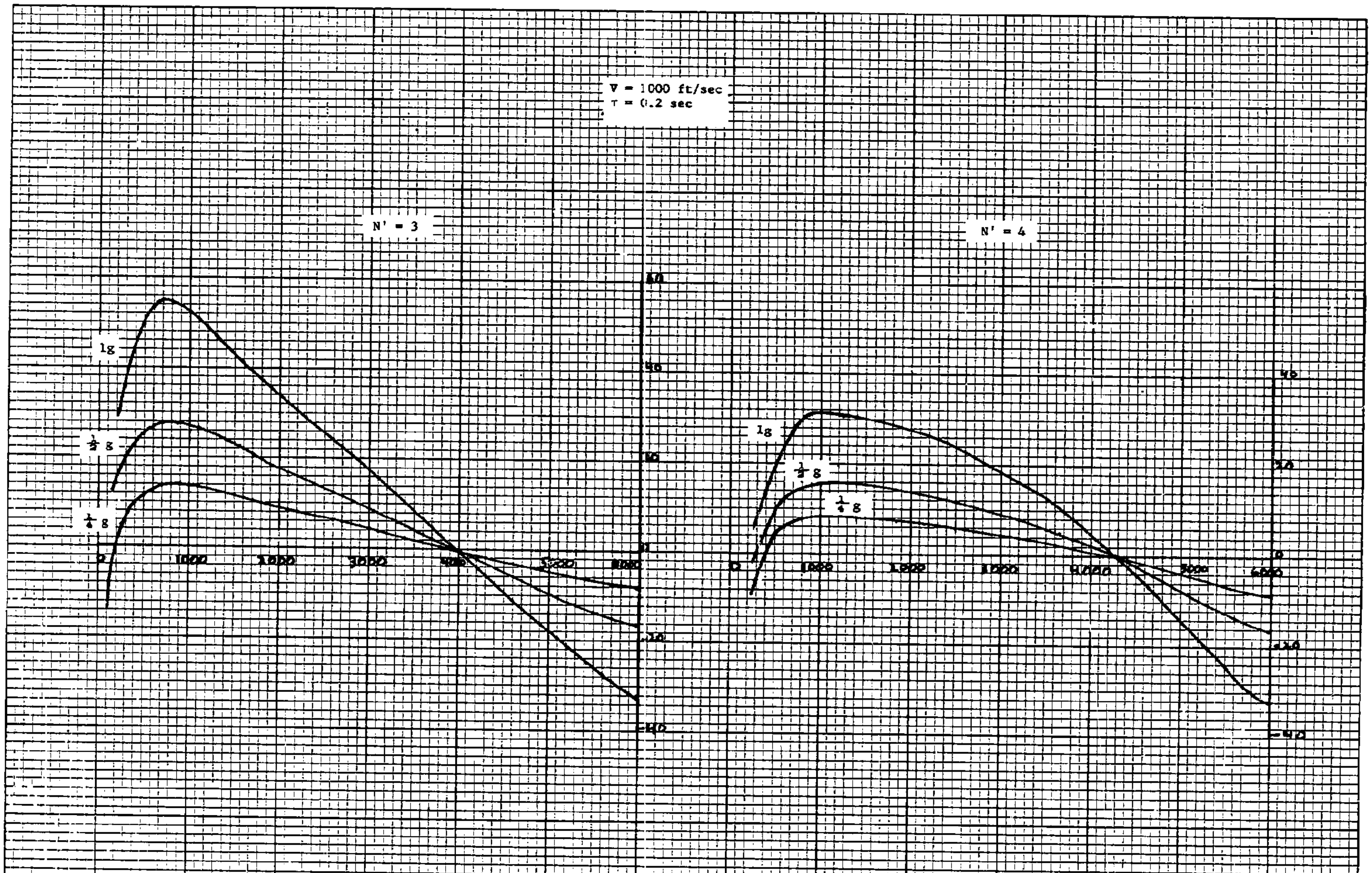
Graph 8 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Heading Error



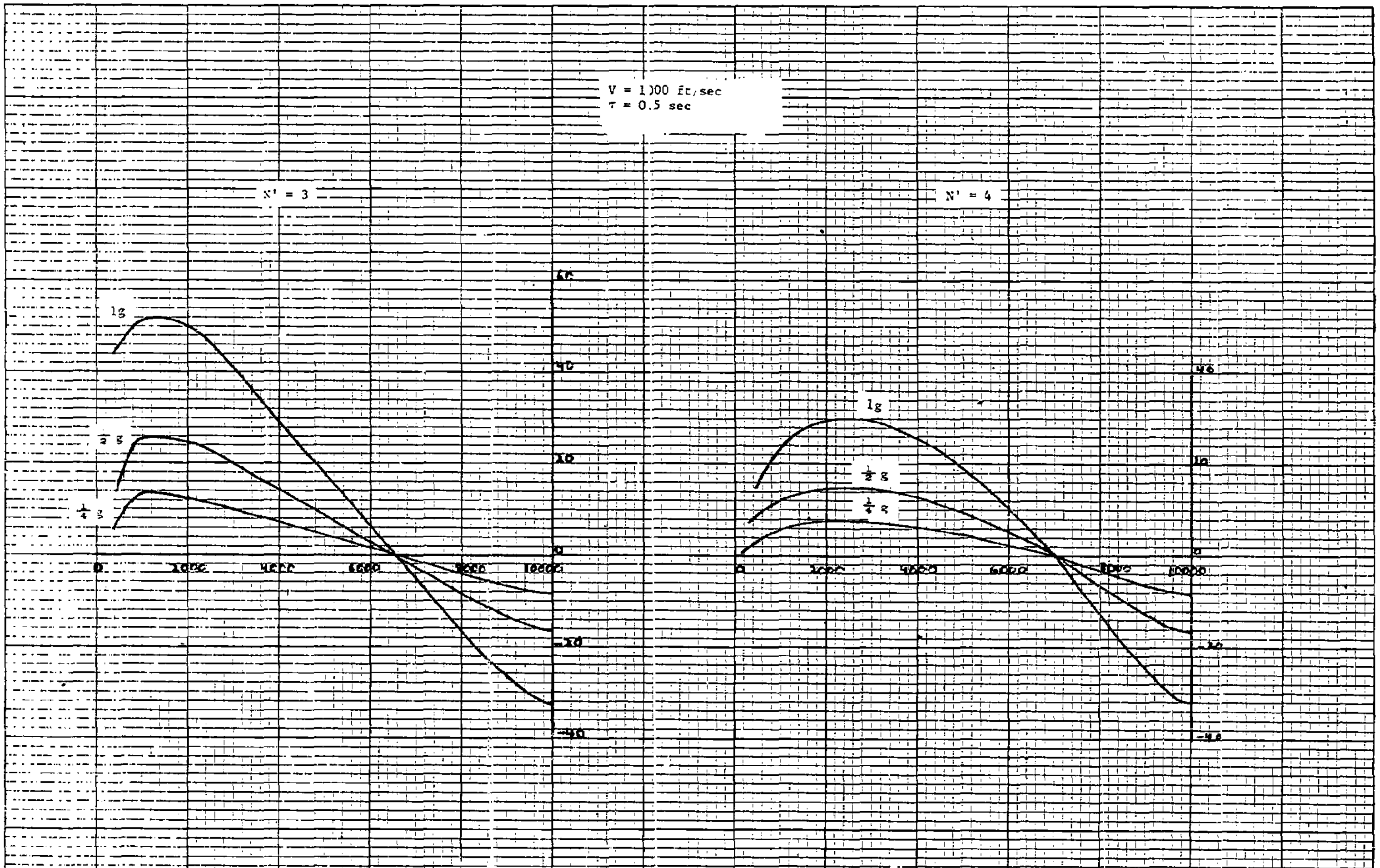
Graph 9 - Required Missile Acceleration (ft/sec2) vs Range (ft) for an Initial Heading Error



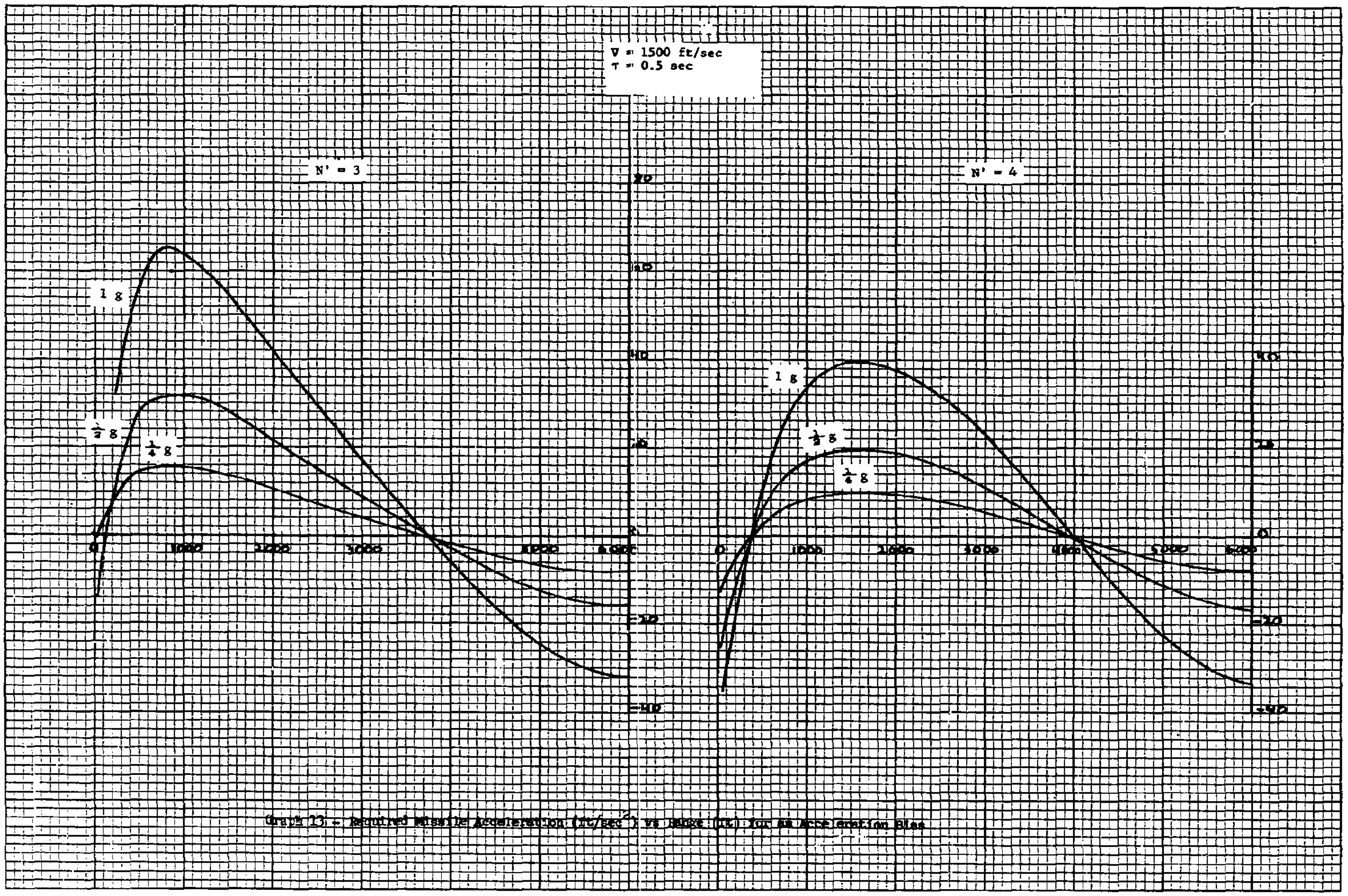
Graph 17. Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Acceleration Bias



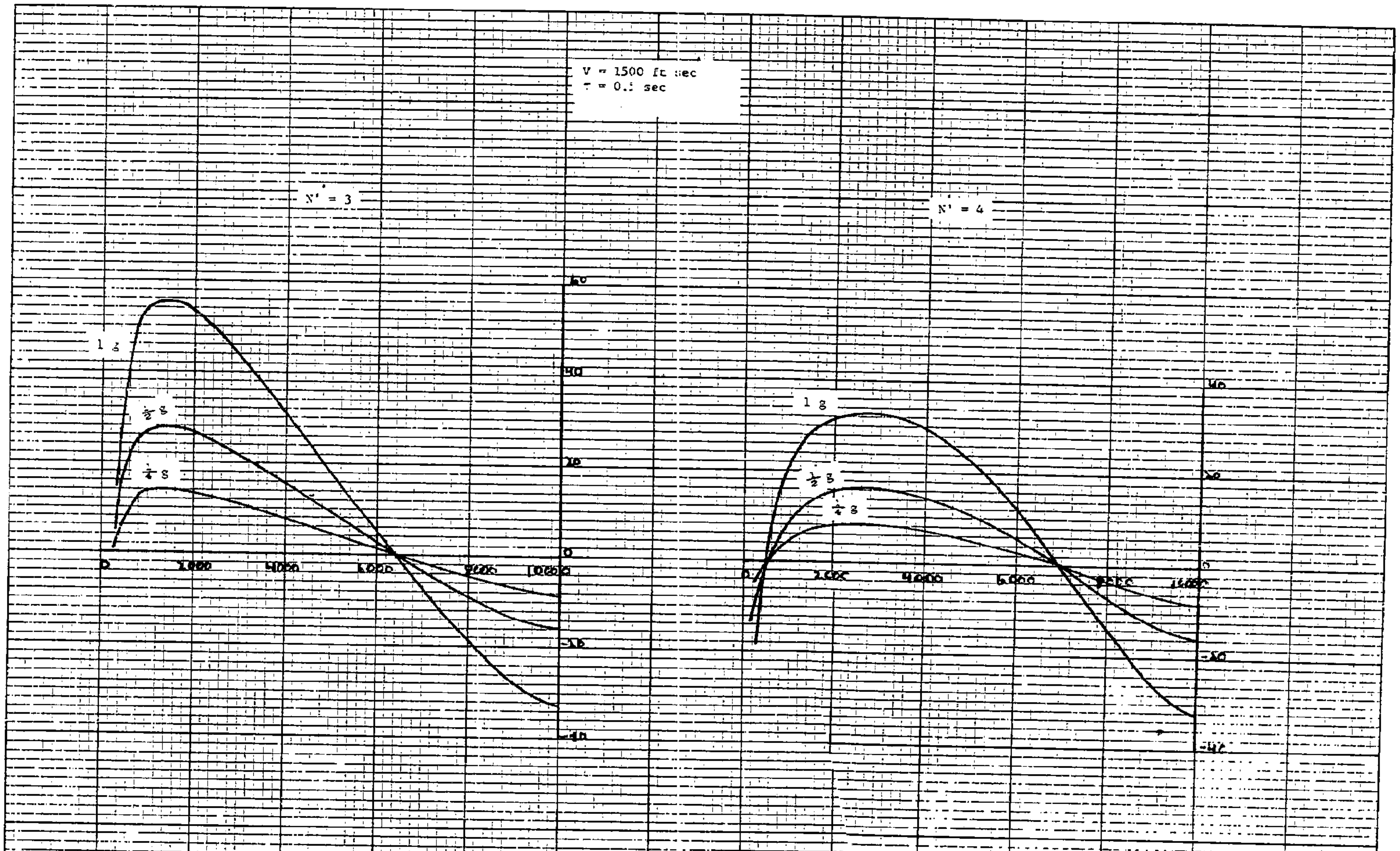
Graph II - Required Missile Acceleration (ft/sec²) vs Range (ft) for an Acceleration Bias



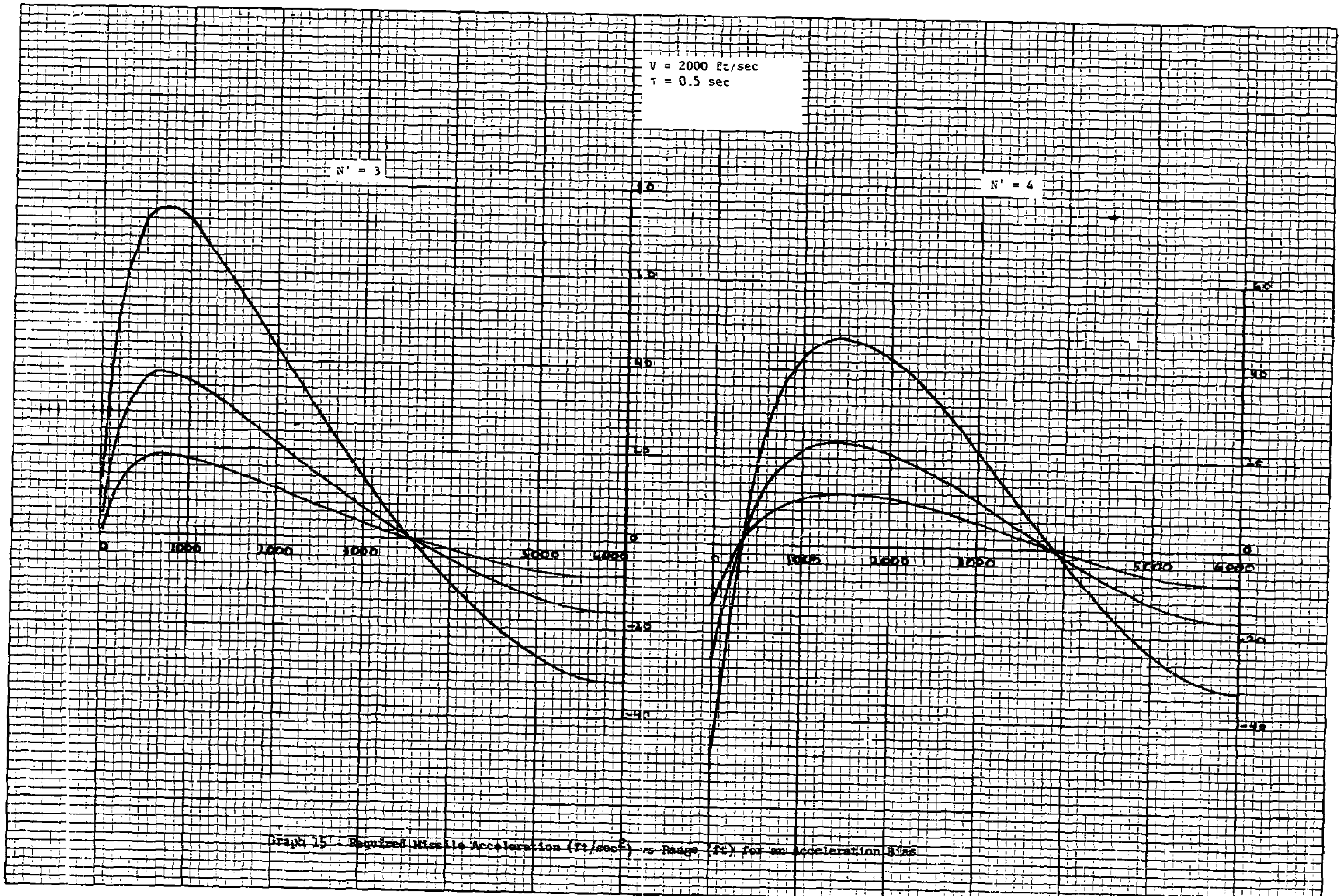
Graph 12 – Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Acceleration Bias



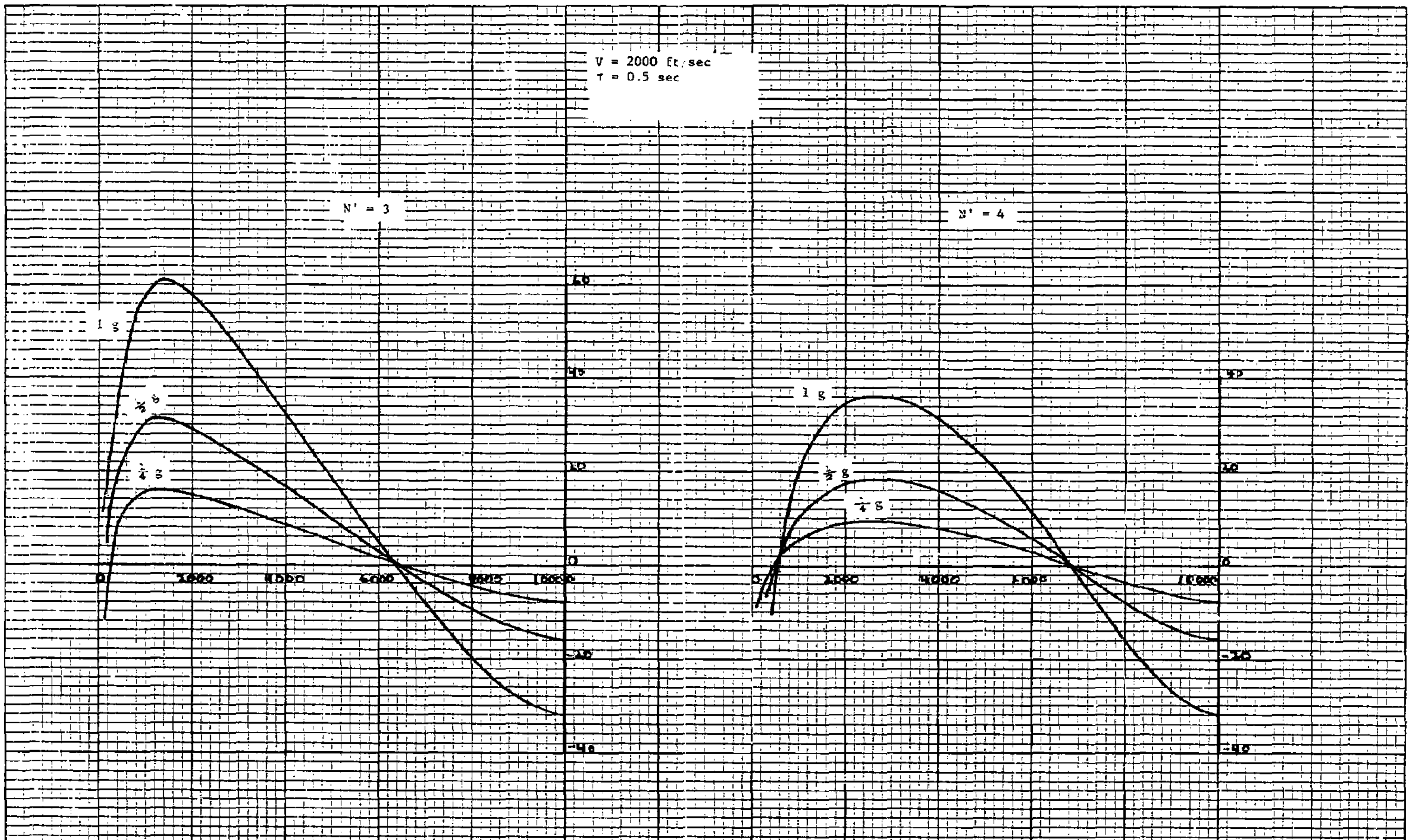
Graph 13 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Acceleration Bias



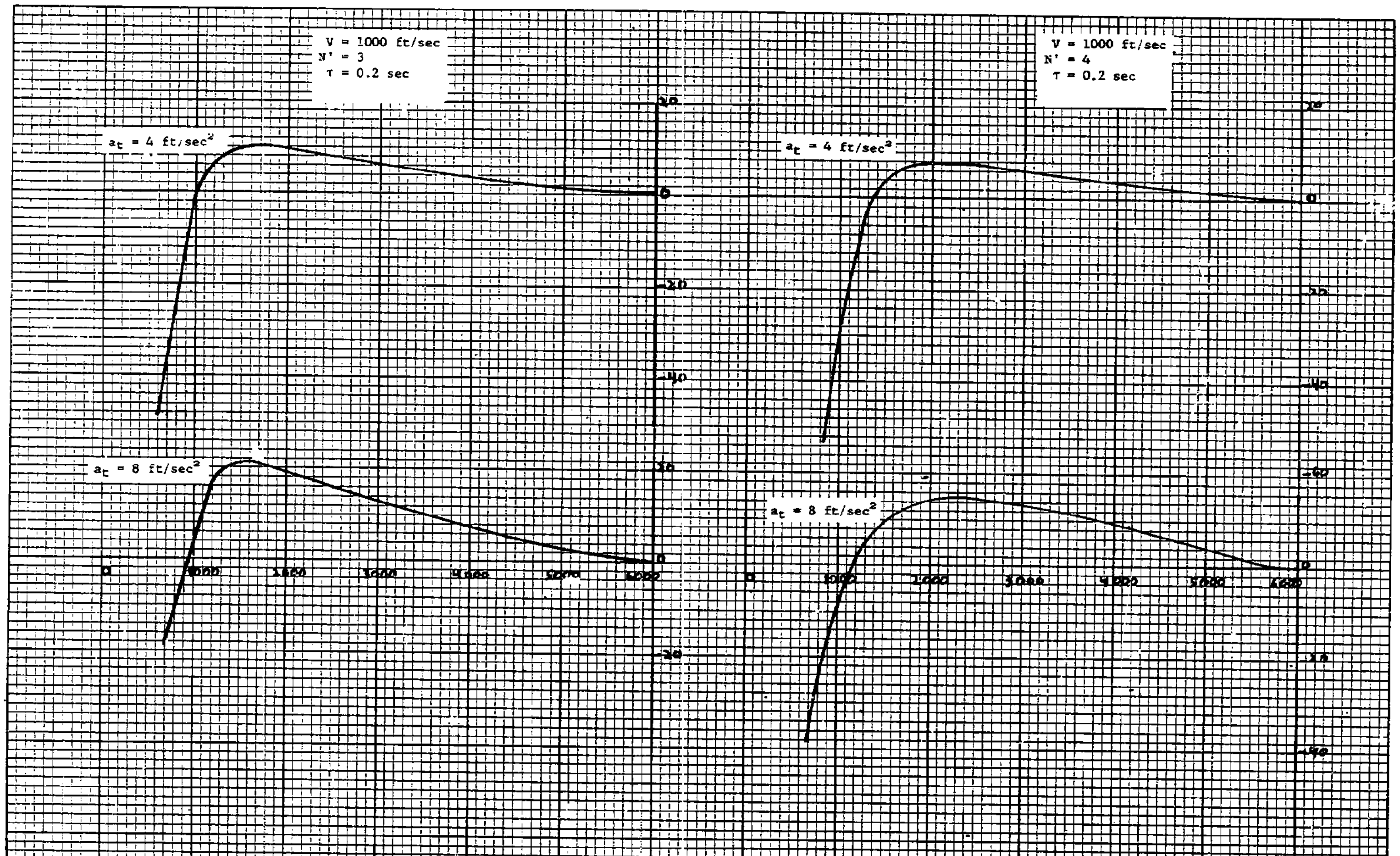
Graph 11. Required Missile Acceleration (ft/sec²) vs Range (ft) for an Acceleration Bias



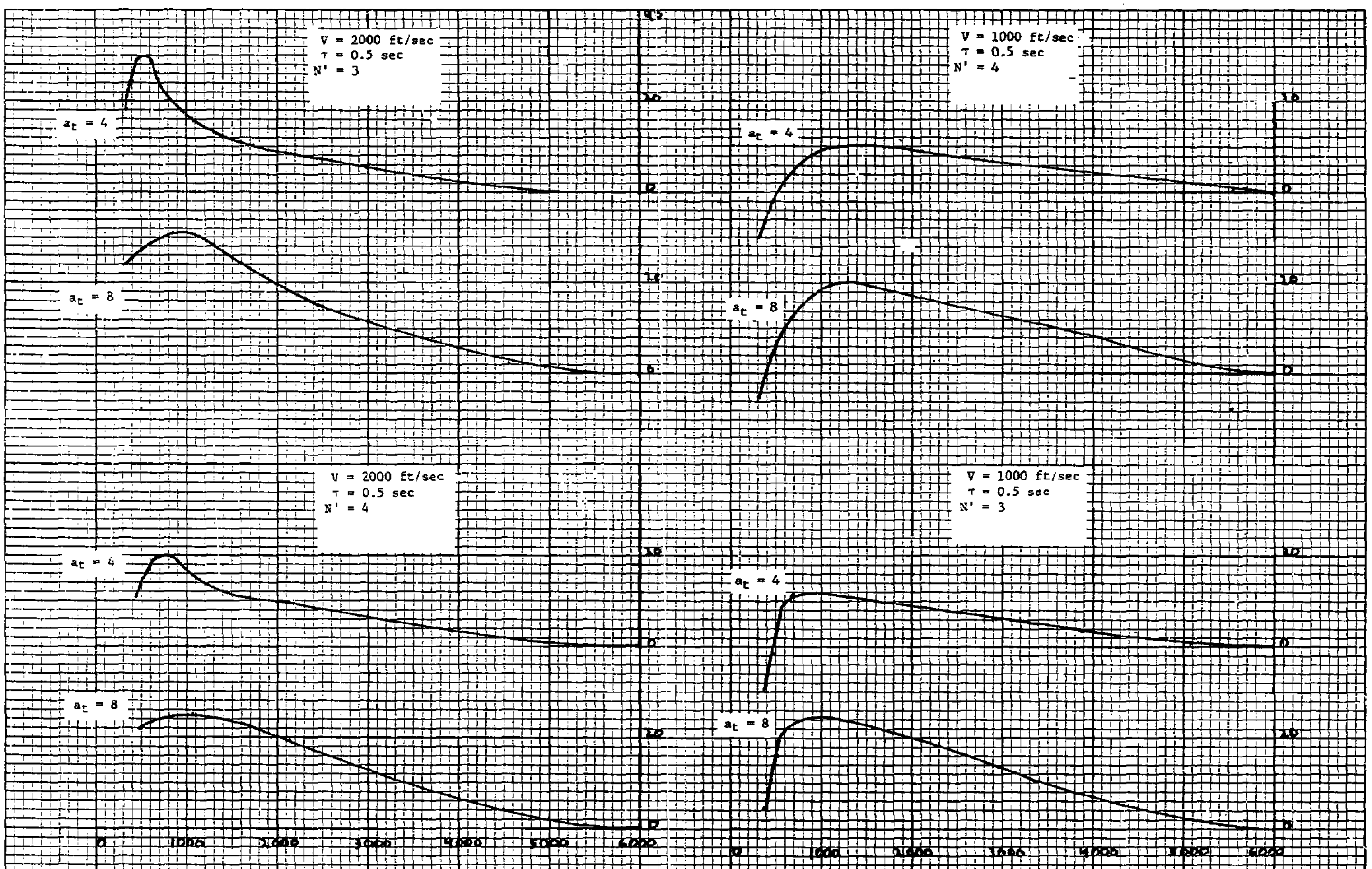
Graph 15 - Required Missile Acceleration (ft/sec²) vs Range (ft) for an Acceleration Bias



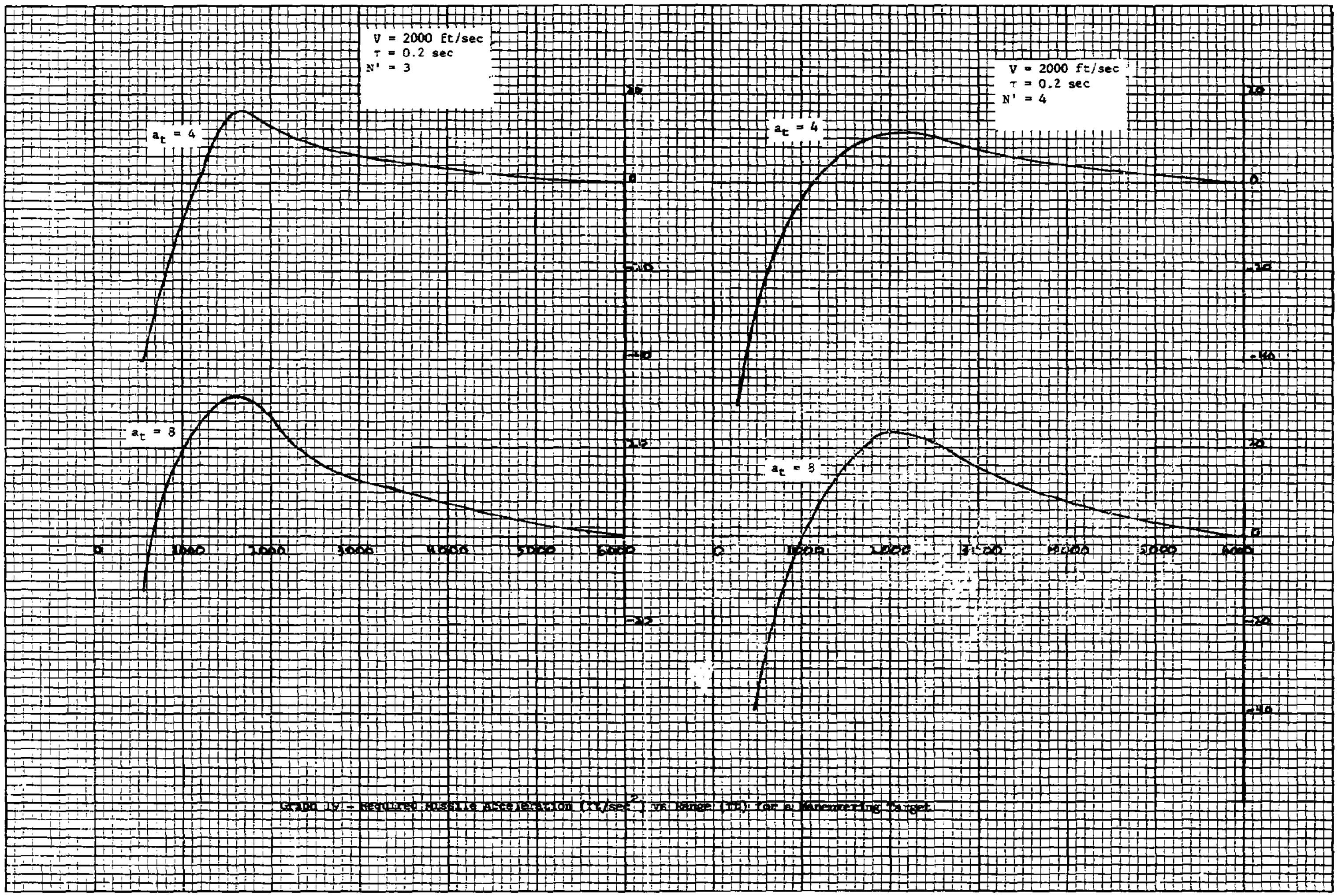
Graph 16 — Required Missile Acceleration (ft/sec²) vs Range (ft) for an Acceleration Bias)



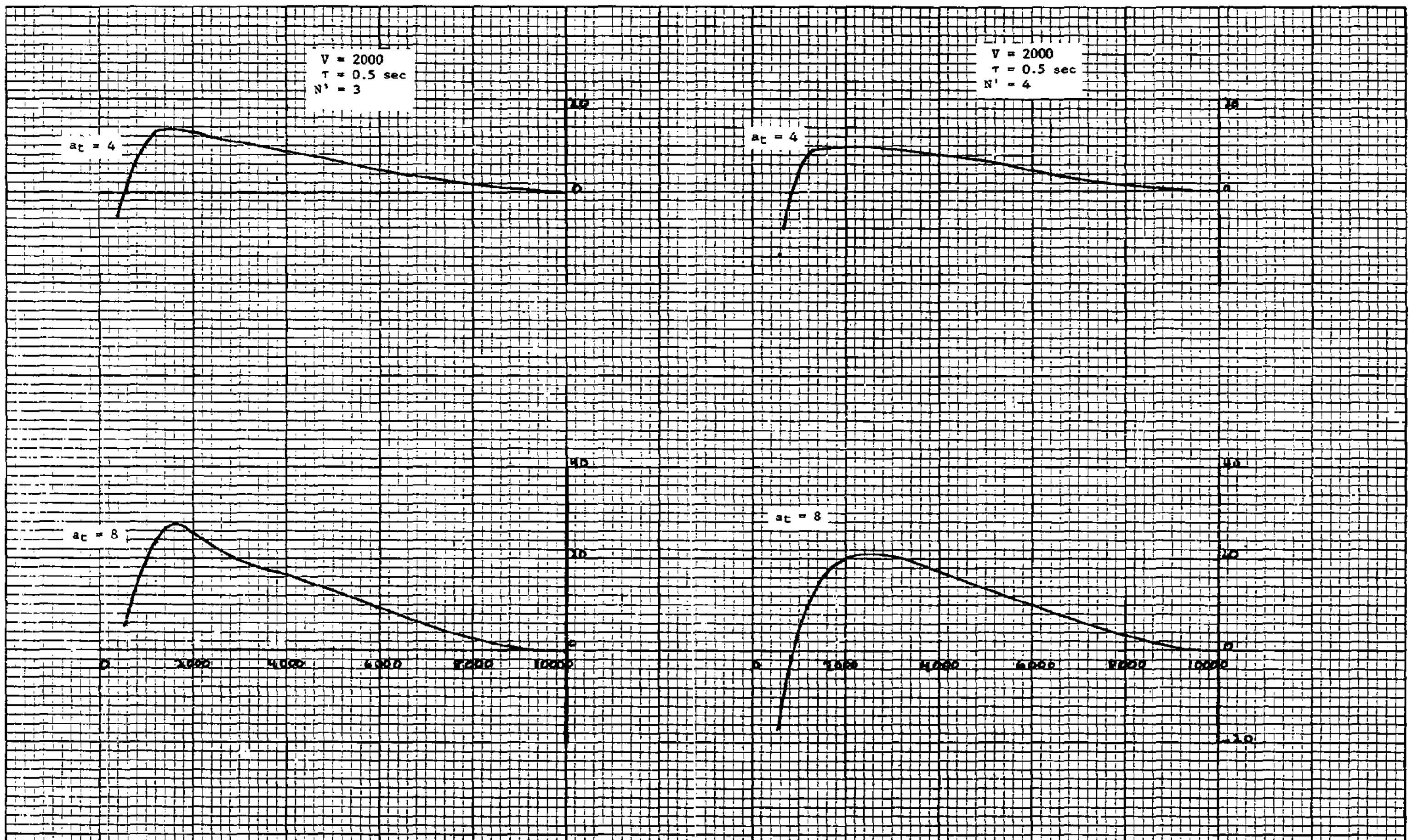
Graph 17 – Required Missile Acceleration (ft/sec^2) vs Range (ft) for a Maneuvering Target



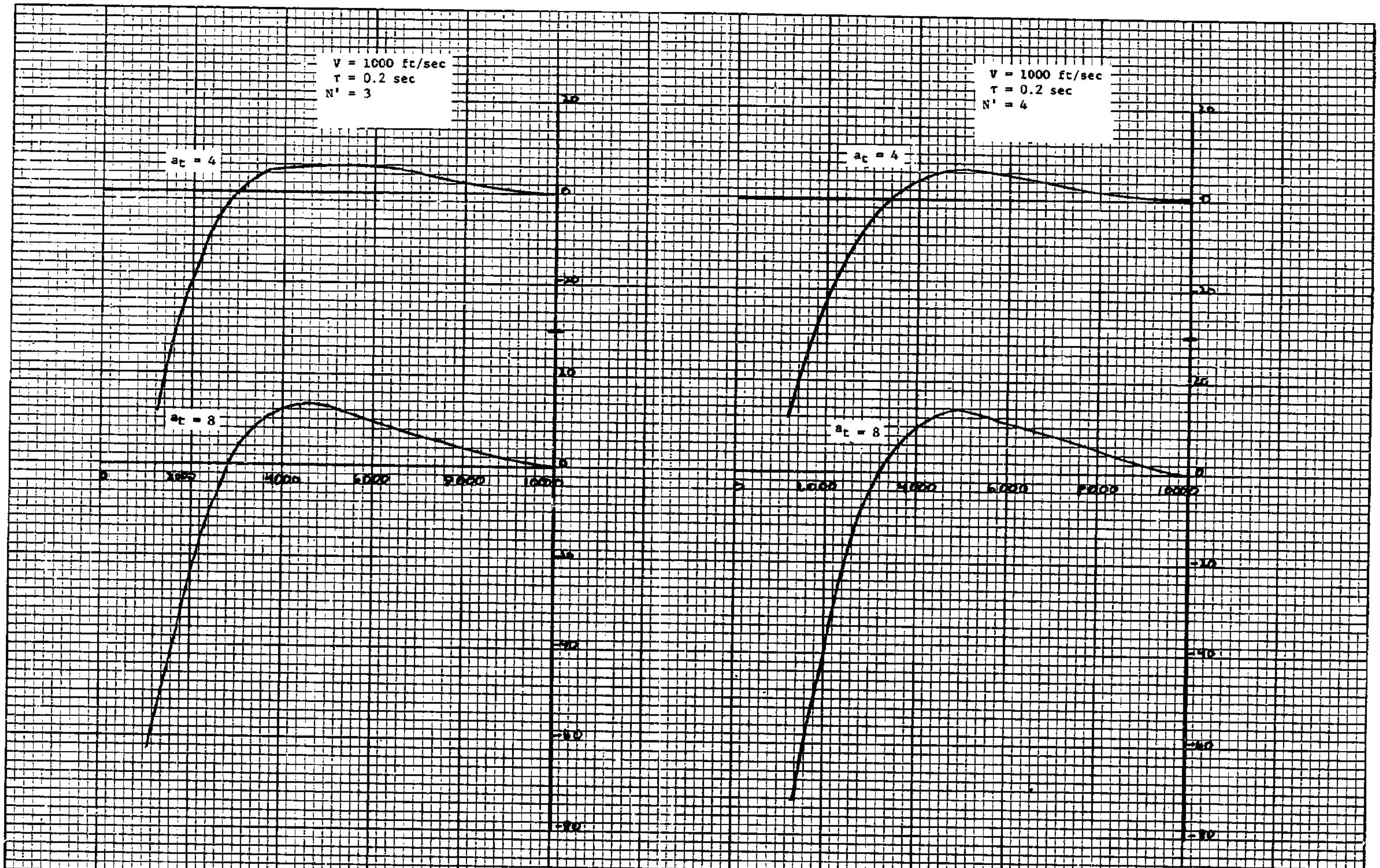
Graph 18— Required Missile Acceleration (ft/sec^2) vs Range (ft) for a Maneuvering Target



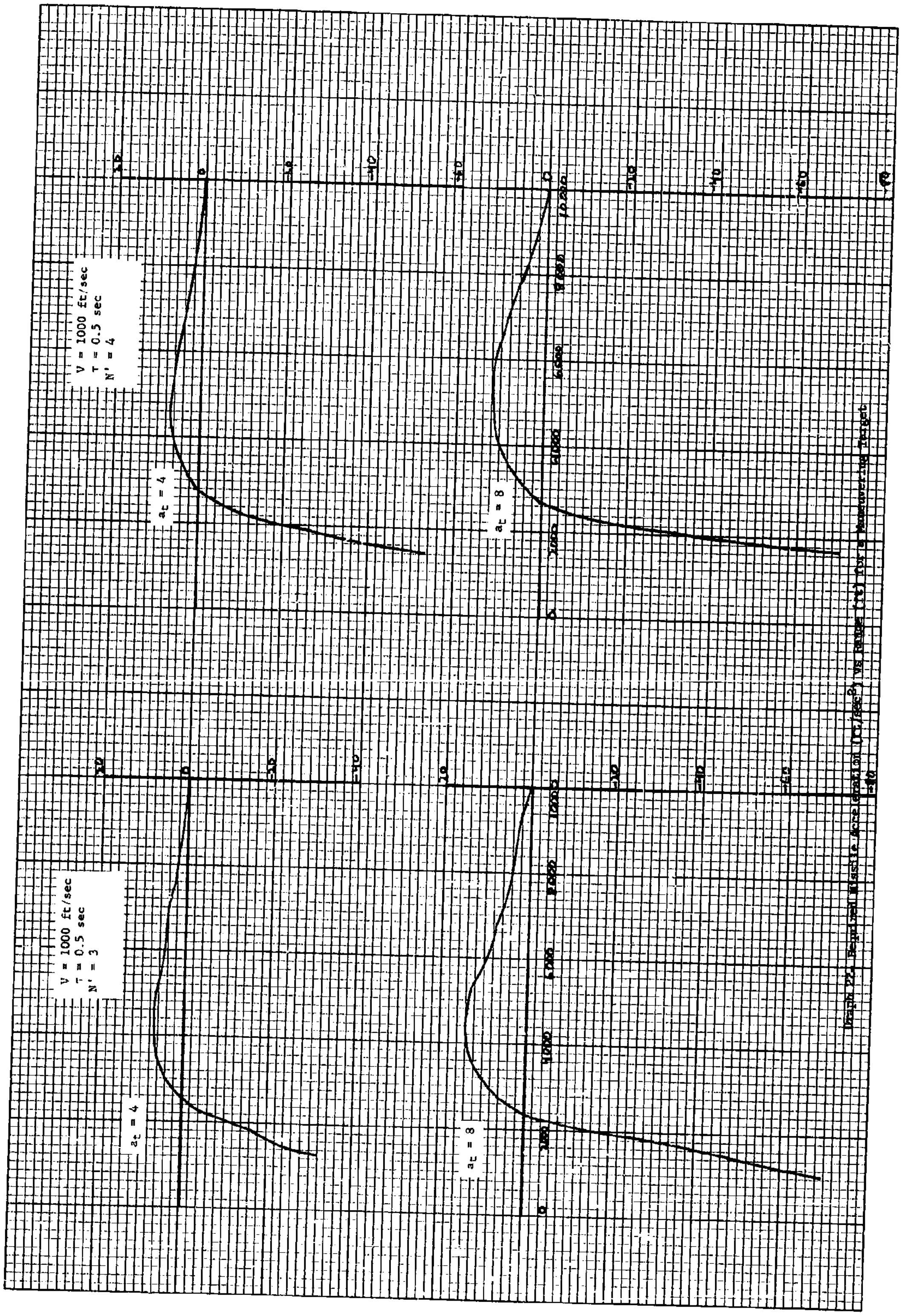
Graph IV - Required Missile Acceleration (ft/sec^2) vs Range (ft) for a Maneuvering Target



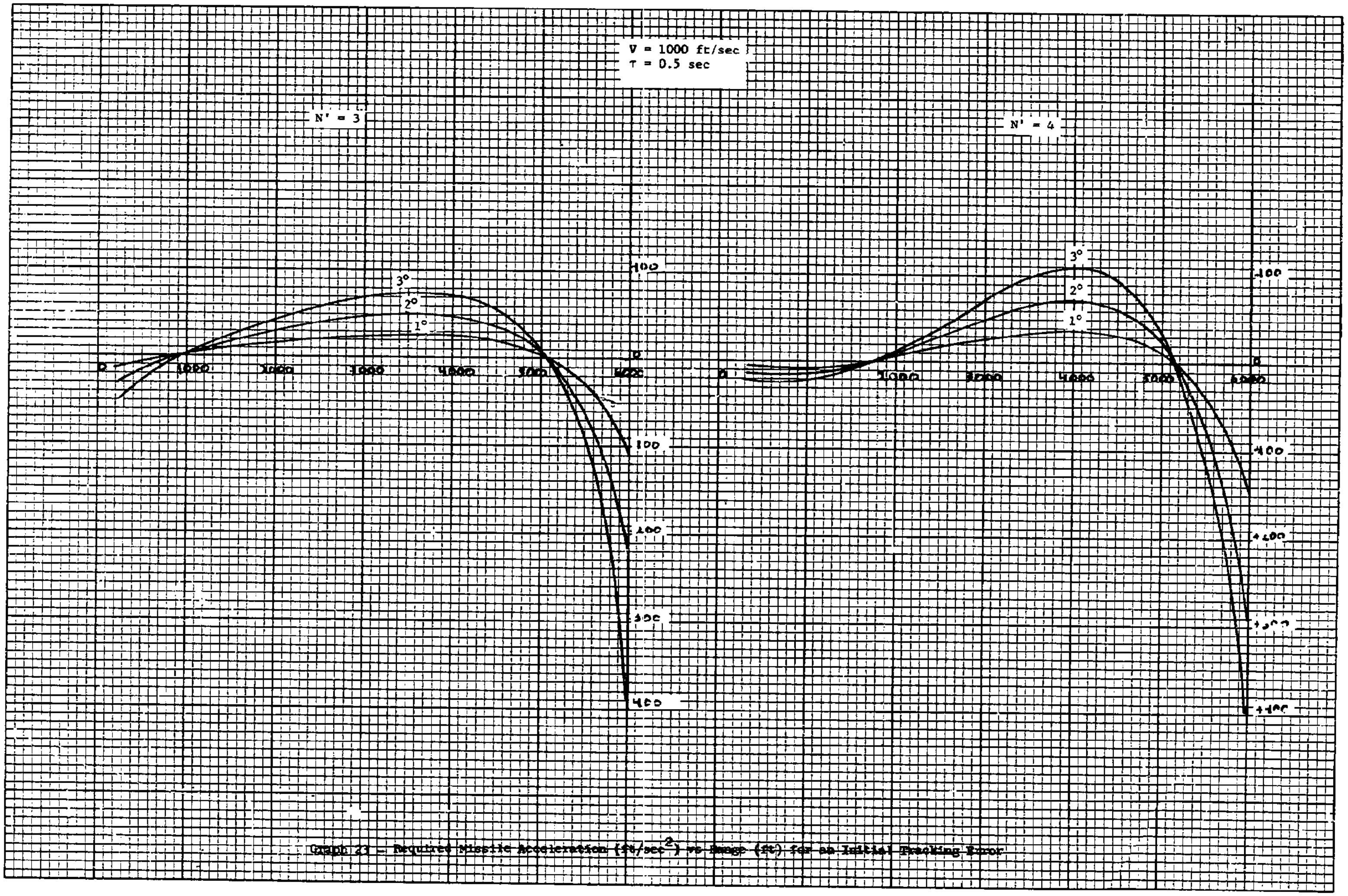
Graph 20 – Required Missile Acceleration (ft/sec^2) vs Range (ft) for a Maneuvering Target



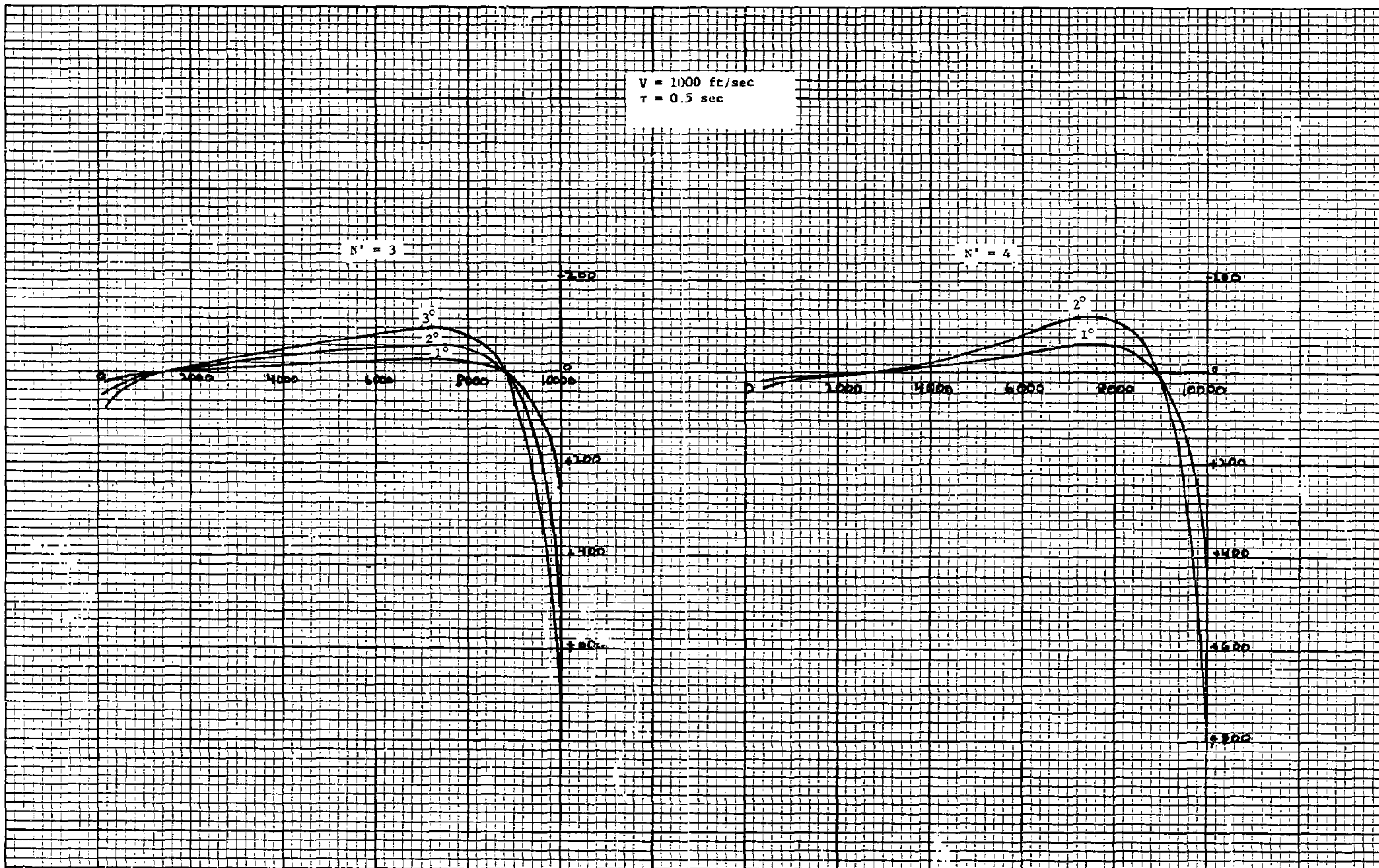
Graph 21. Required Missile Acceleration (ft/sec^2) vs Range (ft) for a Maneuvering Target



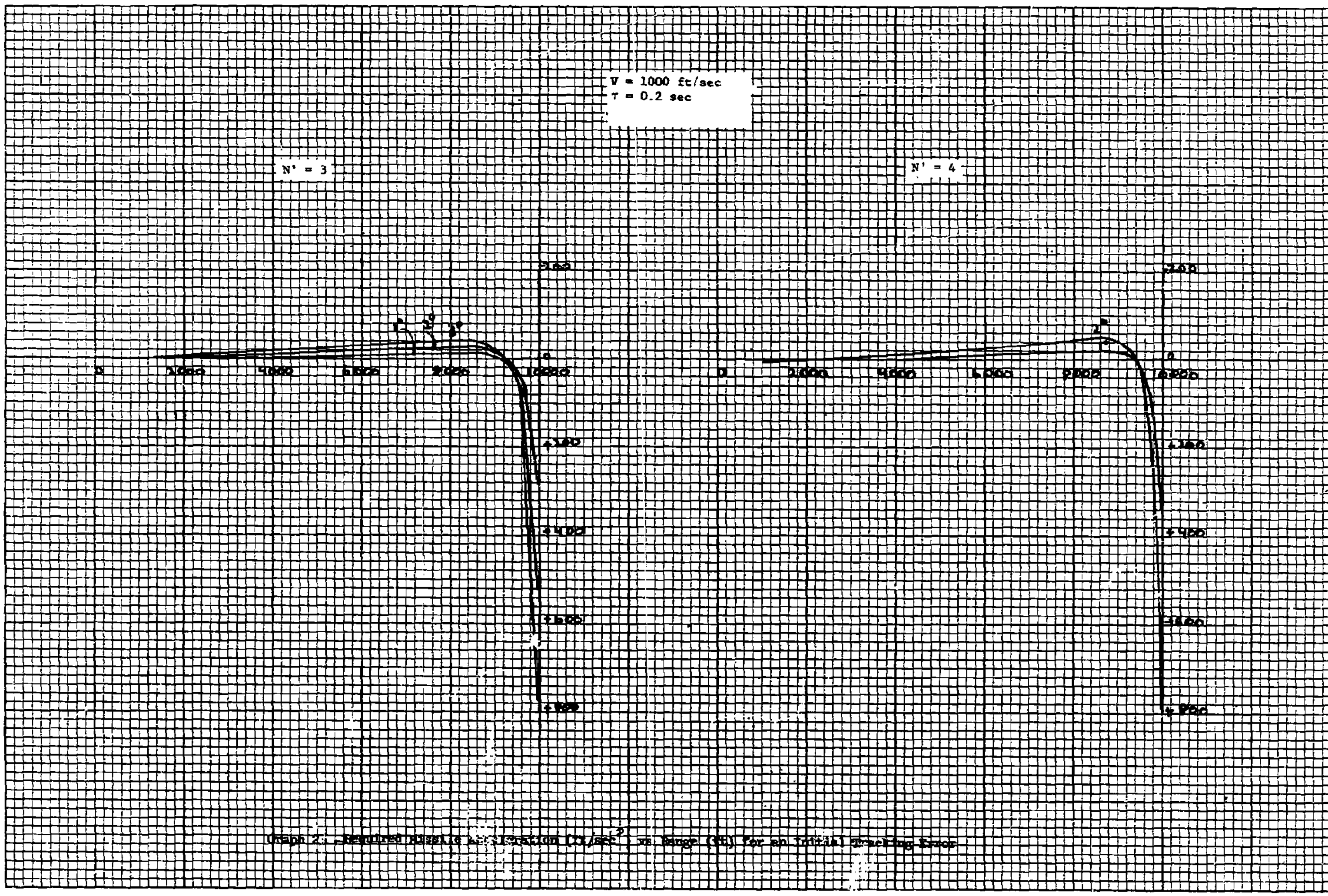
Graph 22. Required Missile Acceleration (ft/sec^2) vs Range (ft) for a Maneuvering Target



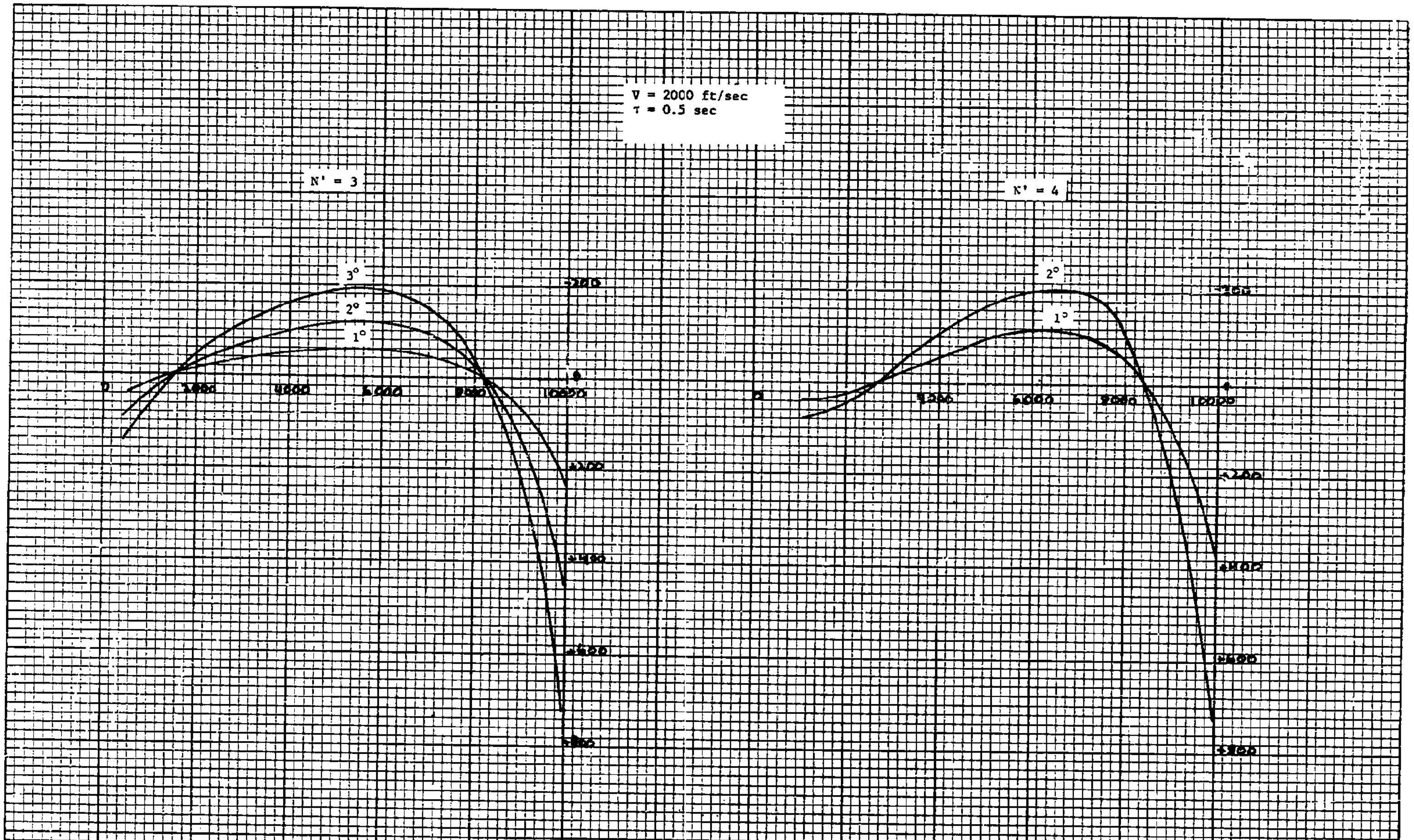
Graph 23 – Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Tracking Error



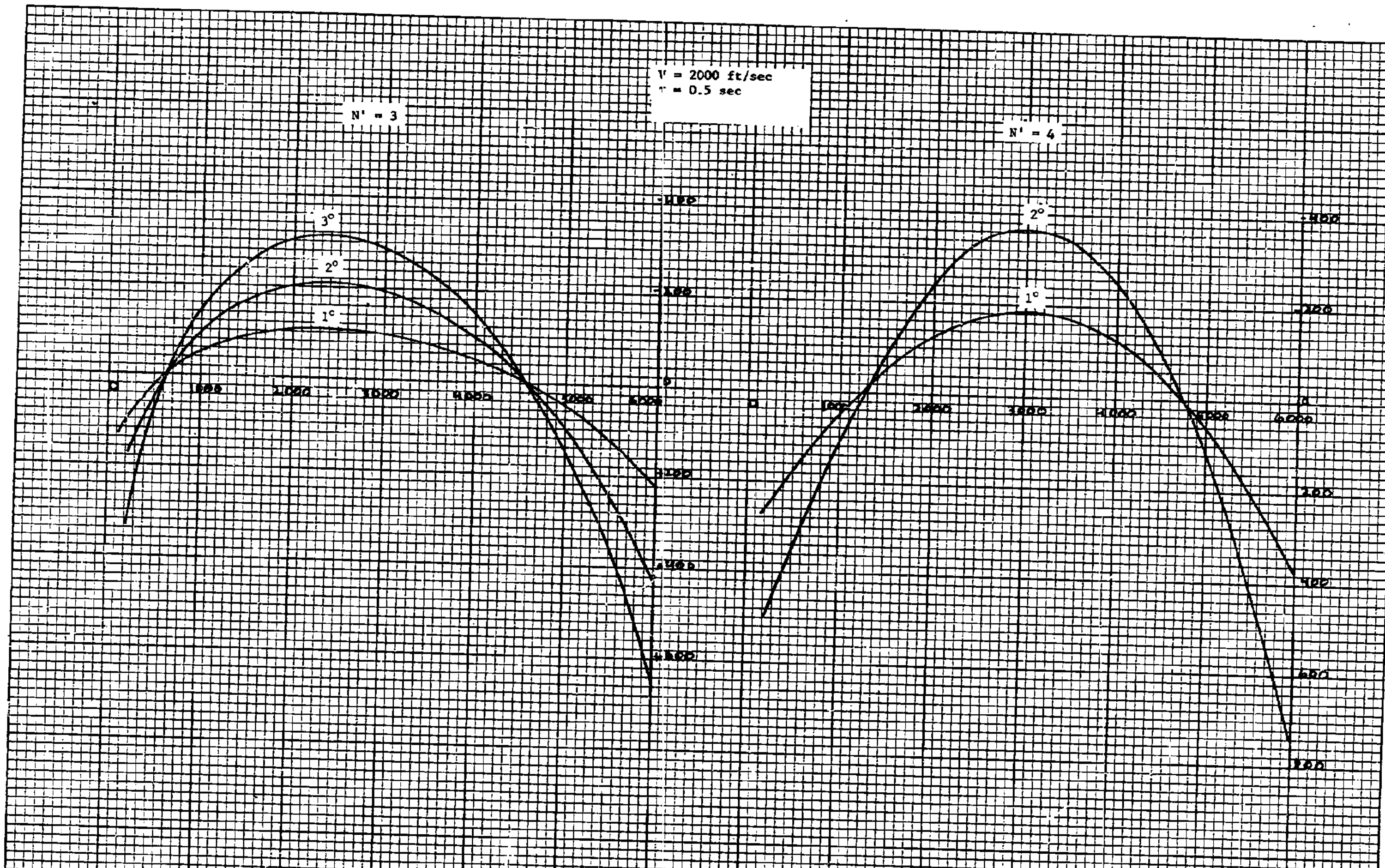
Graph 24 — Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Tracking Error



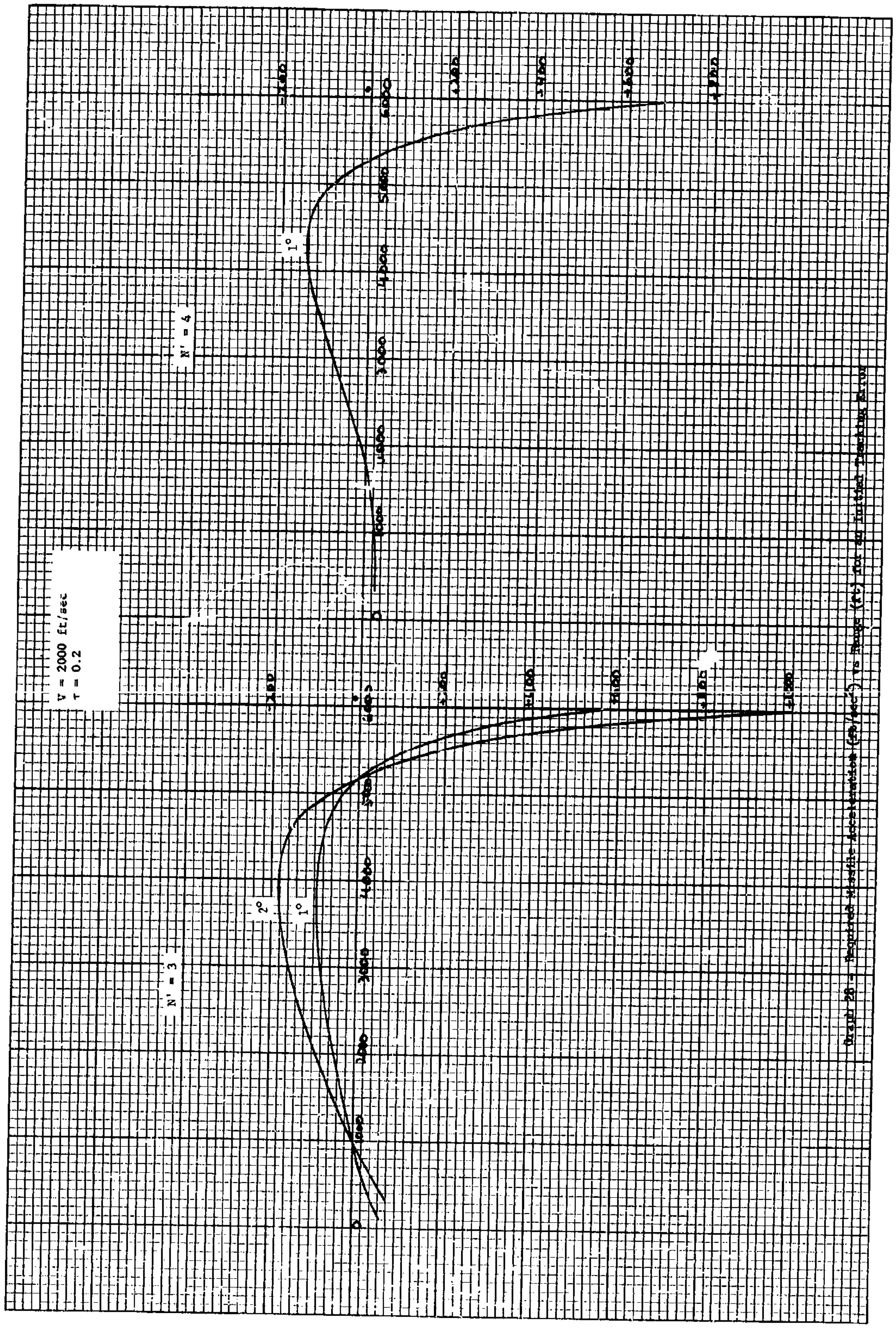
Graph 2. —Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Tracking Error



Graph 26 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Tracking Error



Graph 27 - Required Missile Acceleration (ft/sec²) vs Range (ft) for an Initial Tracking Error



Graph 28 - Required Missile Acceleration (ft/sec^2) vs Range (ft) for an Initial Tracking Error

17 May 1963

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